ME571/Geol571 Geology and Economics of Strategic and Critical Minerals

Commodities: Tellurium

Virginia T. McLemore

ASSIGNMENT

- Barker, J. M., and McLemore, V. T., 2005, Sustainable development and Industrial minerals: Mining Engineering, December, p. 48-52, http://geoinfo.nmt.edu/staff/mclemore/documents/sustdevIM.pdf
- McLemore, V. T., and Dennis Turner, D., 2006, Sustainable development and exploration: Mining Engineering, February, p. 56-61, http://geoinfo.nmt.edu/staff/mclemore/documents/sustdev.pdf

Mickey Fulp: 'We Need to Eliminate the Zombie Miners'

Monday March 23, 2015, 10:40am PDT

By Charlotte McLeod+ • Exclusive to Gold Investing News

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Mercenary Geologist Mickey Fulp wasn't able to make it to PDAC this year due to adverse weather conditions, but that doesn't mean he wasn't watching what went on at the conference. In this post-PDAC video, Fulp delivers interesting information about the finances of some companies in attendance, also touching on issues currently plaguing many major gold miners.

In terms of PDAC, Fulp reiterates his view that the TSX Venture Exchange is home to "zombie miners" that by all rights shouldn't still be listed there — namely "companies that are not solvent." He cites a study done by Tony Simon that indicates that "800 of the 1,200 exploration and mining companies [listed on the exchange] … have negative working capital," and points out that 52 of the companies that paid for a booth at PDAC are on Simon's list.

"How are these companies that have no cash and have in some instances millions of dollars in negative working capital … how do they afford to have an exhibitor booth at PDAC? Because those booths aren't cheap," he quips.

In terms of major gold miners, Fulp answers some questions about subjects he's touched on in videos with the team at Ciper Research, explaining that while such companies are inconsistent in the way they report their costs, it's also partially an issue with reporting regulations. "It's a combination of

http://resourceinvestingnews.com/84838-mickey-fulp-we-need-to-eliminate-the-zombie-miners.html?pmc=E-1&MyID=ginger@nmbg.nmt.edu&utm_source=Resource+Investing+News&utm_campaign=a0cc415742-RSS_EMAIL_CAMPAIGN&utm_medium=email&utm_term=0_f83d87db0f-a0cc415742-248853569

http://www.visualcapitalist.com/not-a-drop-to-drink-americas-water-crisis/?utm_source=Visual+Capitalist+Infographics+%28All%29&utm_campaign=9248b63fb1-Most_Valuable_Cash_Crop&utm_medium=email&utm_term=0_31b4d09e8a-9248b63fb1-43004761

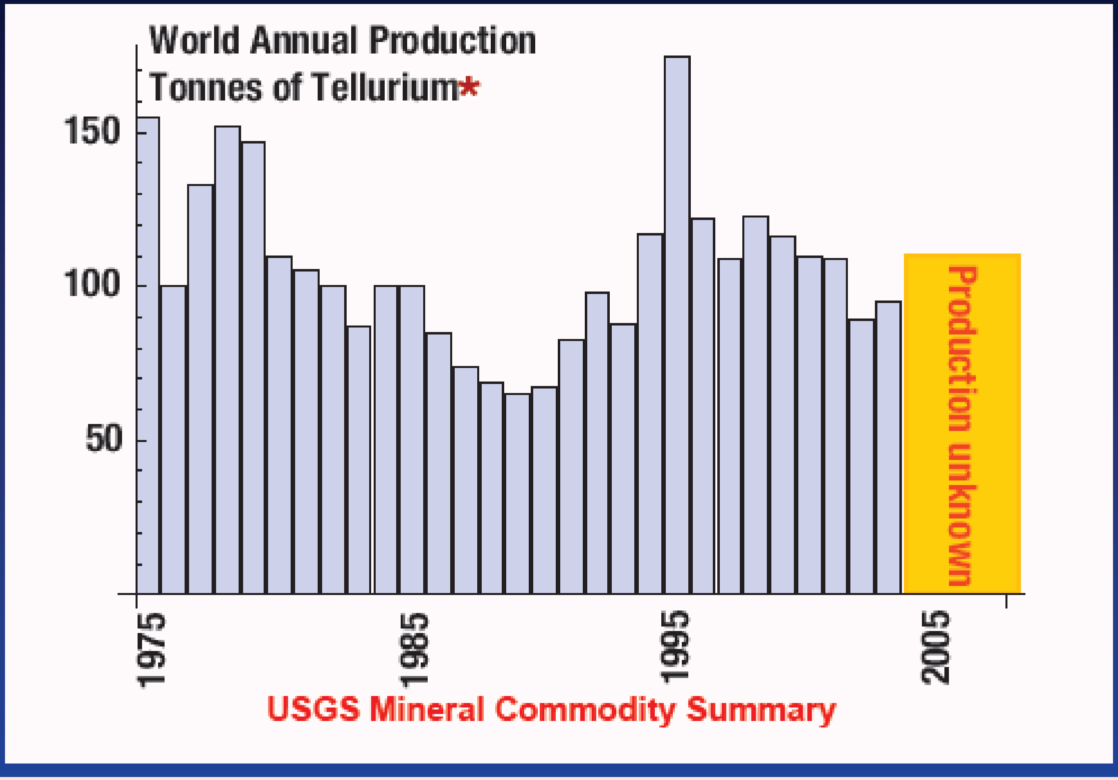

AND THEN THERE'S THE "HIDDEN WATER" IN WHAT WE CONSUME AND ITEMS WE USE EVERY DAY.
A 60-WATT BULB
can use up to
5 GALLONS
OF WATER
for every hour it's left on.
A pound of beef, from
farm to plate, uses
1,800 GALLONS
OF WATER.
WE USE PLENTY OF WATER EVERY DAY, BUT WE NEED TO FIND A WAY TO CONSERVE.
CONSERVATION
THERE ARE SMALL THINGS WE CAN ALL DO:
Old toilets use 7 GALLONS per flush.
New toilets can use as little as 1 GALLON.
INSTALLING WATER-EFFICIENT FIXTURES
CAN REDUCE A HOUSEHOLD'S DAILY
WATER USE BY
35 PERCENT.
Replacing grass lawns with
native plants (especially in dry
communities) can save over
15,000 GALLONS
PER YEAR.
AND BIG THINGS THAT INDUSTRIES CAN DO:
Farms that change to overhead or drip irrigation, from traditional
surface irrigation, could significantly improve agricultural water
efficiency, while preventing runoff and food waste.

INTRODUCTION

INTRODUCTION

Tellurium – critical in use, possible supply risk

- 0.0000001% of earth's crust (compare gold -- 0.0000004%)
- Almost all comes from by-product of copper smelting
- Key in Cd-Te thin-film solar photovoltaics



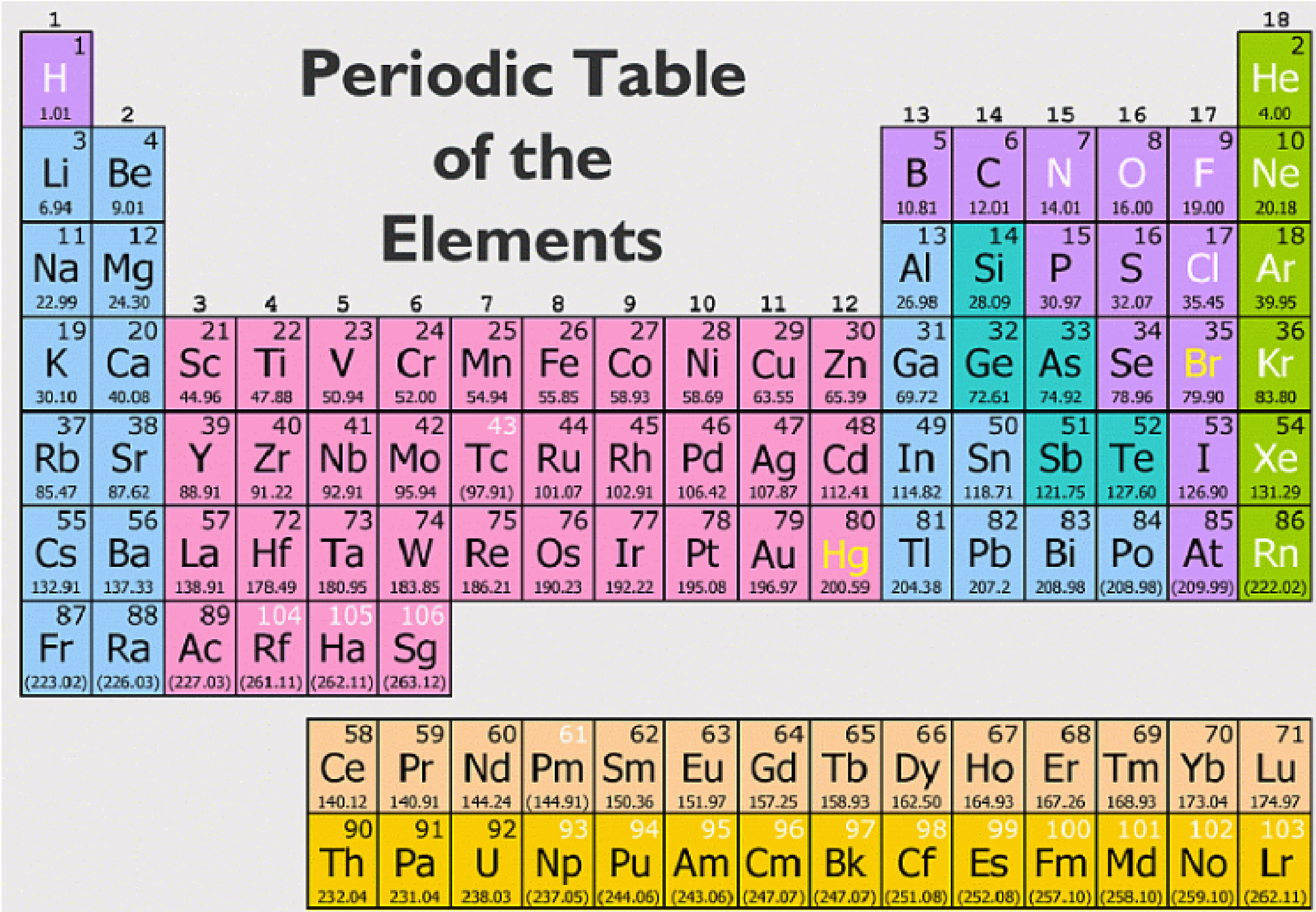


Figure 1. Periodic table of the elements. The rare earth elements comprise 15 elements, which range in atomic number from 57 to 71, including lanthanum (La) to lutetium (Lu). The elements are also commonly referred to as "lanthanides." Yttrium (Y, atomic number 39) is also typically included with the rare earth elements group because it shares chemical, physical, and application properties with the lanthanides.

http://pubs.usgs.gov/sir/2010/5220/

Tellurium

- Atomic number of 52
- Atomic weight of 127.6
- One of the least abundant in the crust, ~0.005 ppm
- Brittle, mildly toxic, rare, silver-white
- Tellurium was discovered in gold ores by Franz Joseph Mδller von Reichenstein, the chief inspector of mines in Trannsylvania in 1782
- Technically not a metal, but a metalloid

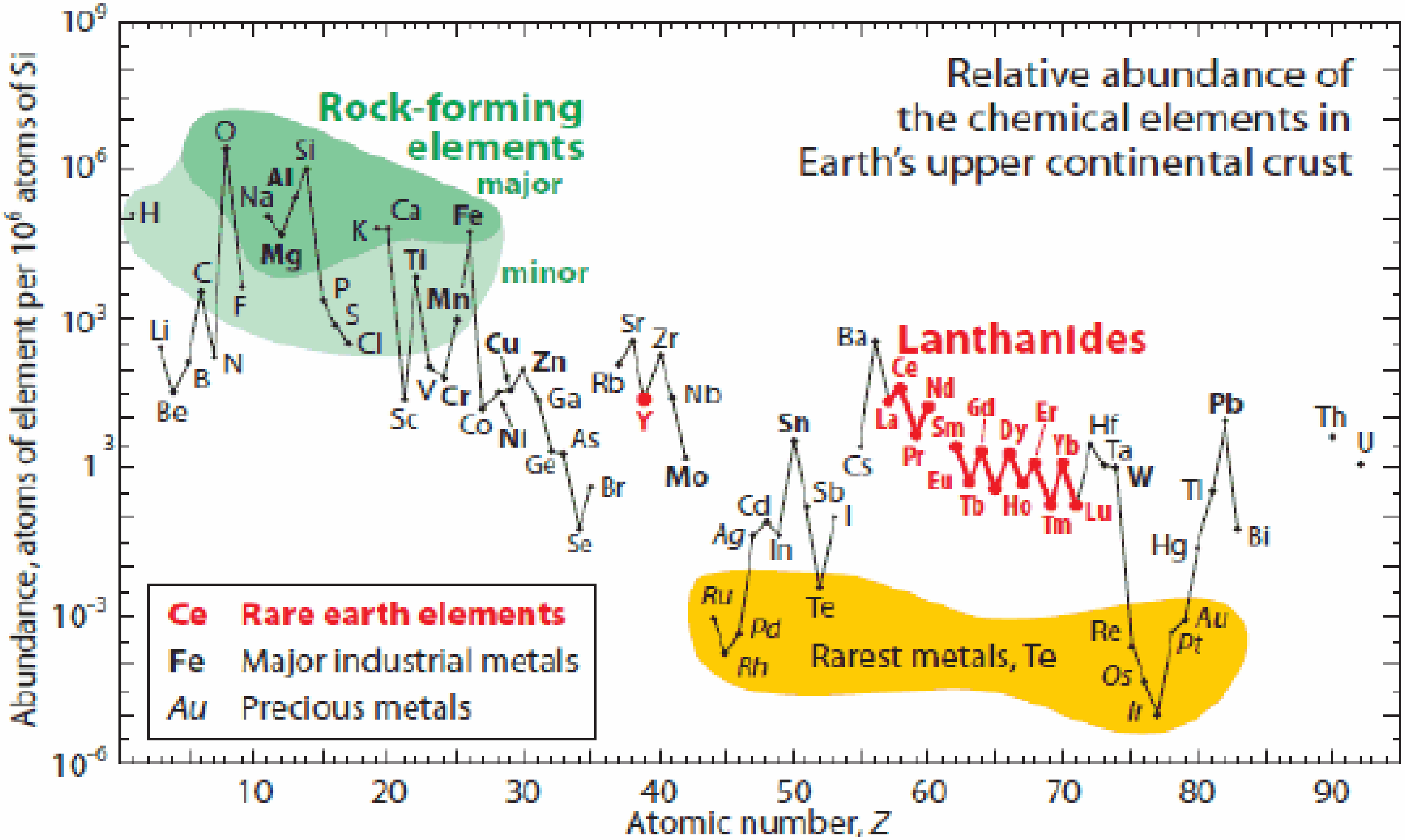
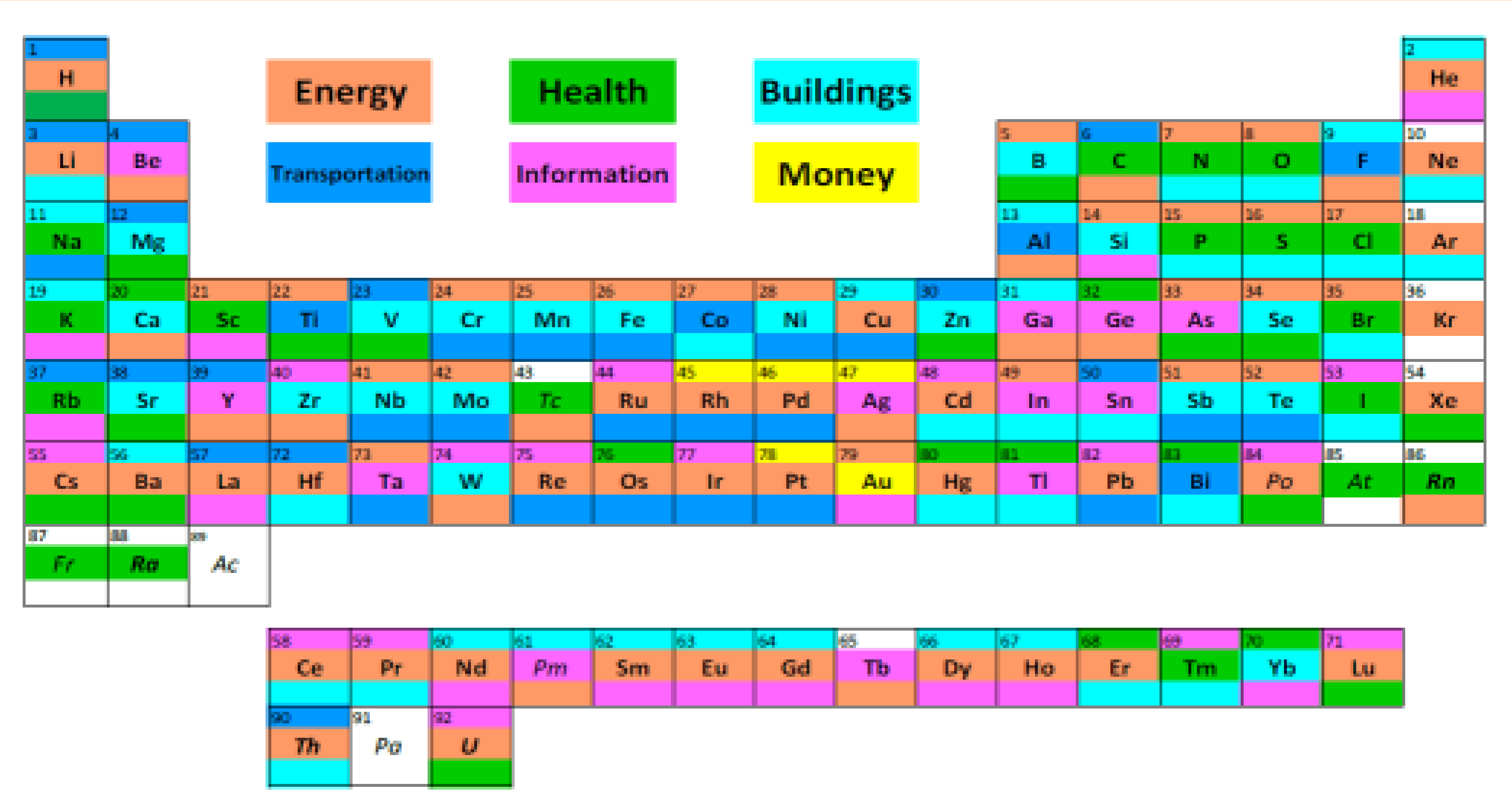


Figure 1 Relative abundance of rare earths (highlighted in red). Figure courtesy of Gordon Haxel, USGS.

Uses of Te

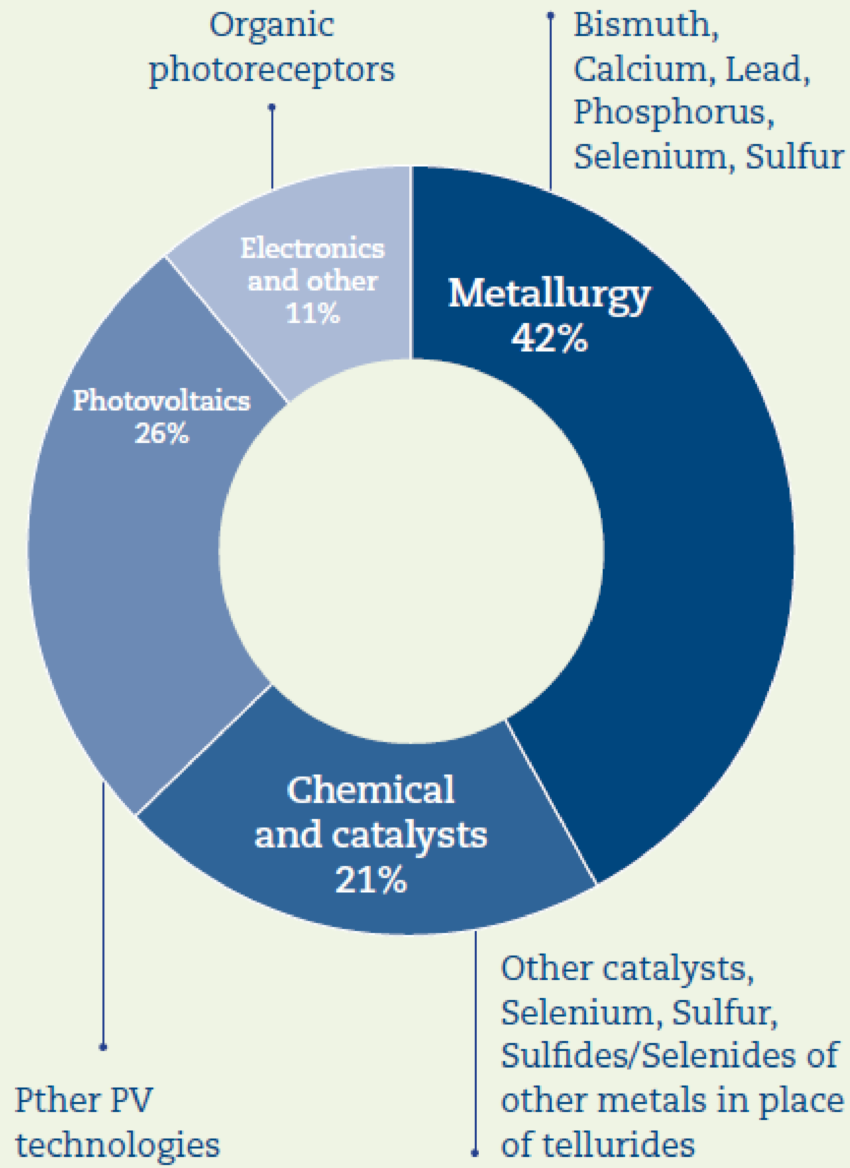


Energy includes the production, transmission , and storage of energy, as well as lighting. Health includes elements necessary for life (food & pharmaceuticals) and for the growing of crops (fertilizers and pesticides). Buildings include materials needed for structures and their general contents and the tools needed to construct them. Transportation includes vehicles and infrastructure, including moving water and wastewater. Information includes communication systems, electronics, and optics. Money includes items that are held as a backing of currencies or to substitute for money, plus jewelry and the arts. From Jon Price, 2015.

Uses of Te

- Alloying additive in steel to improve machining characteristics
- Processing of rubber
- As a component of catalysts for synthetic fiber production
- As pigments to produce various colors in glass and ceramics
- **Thermal imaging devices**
- Thermoelectric cooling devices, such as summertime beverage coolers
- **Thermoelectronics**
- **Solar panels/cells**

End uses and substitutes



Source: USGS (2012)

Uses—TF solar panels

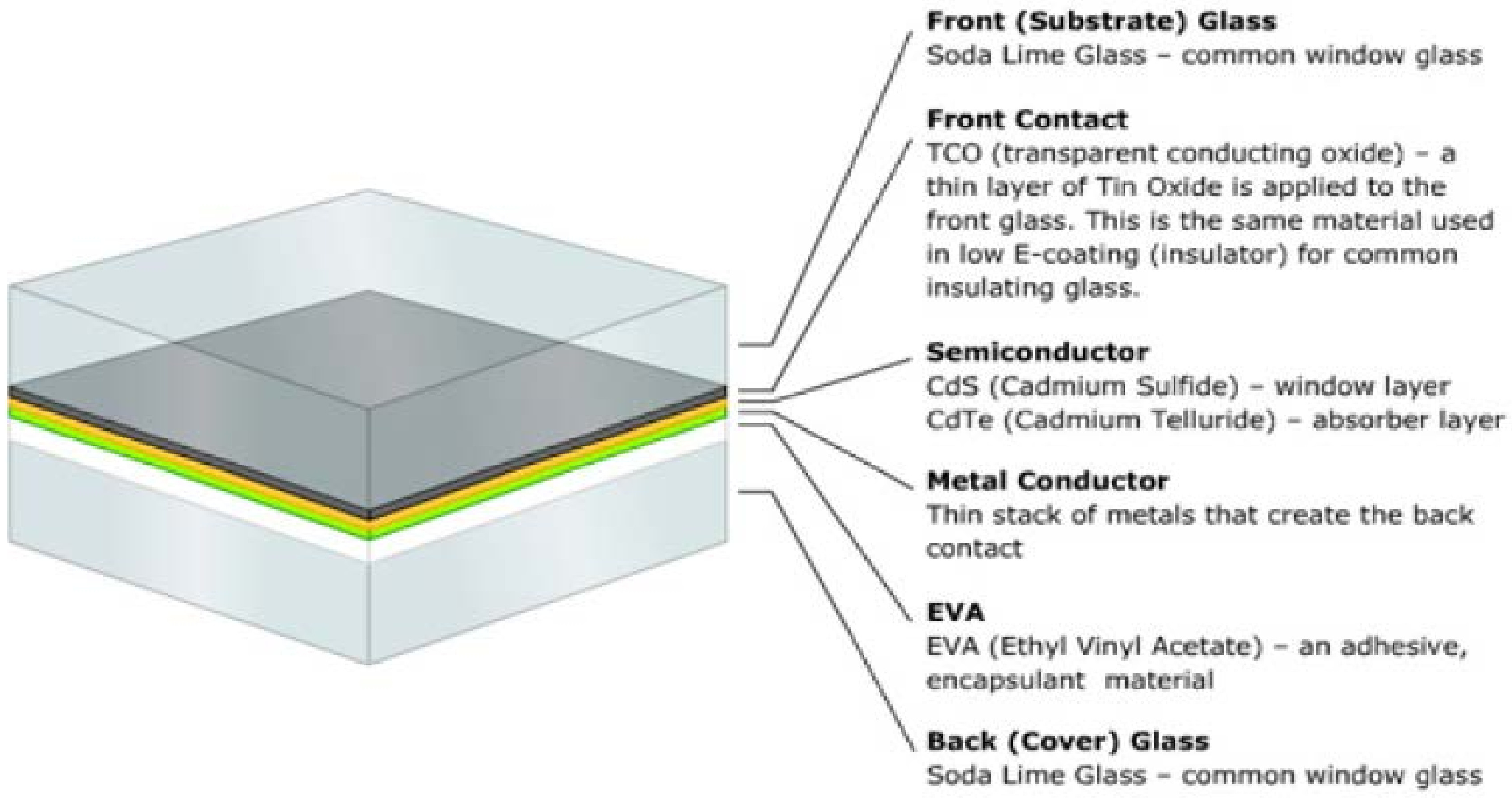


Fig. 1 The First Solar module (www.firstsolar.com)

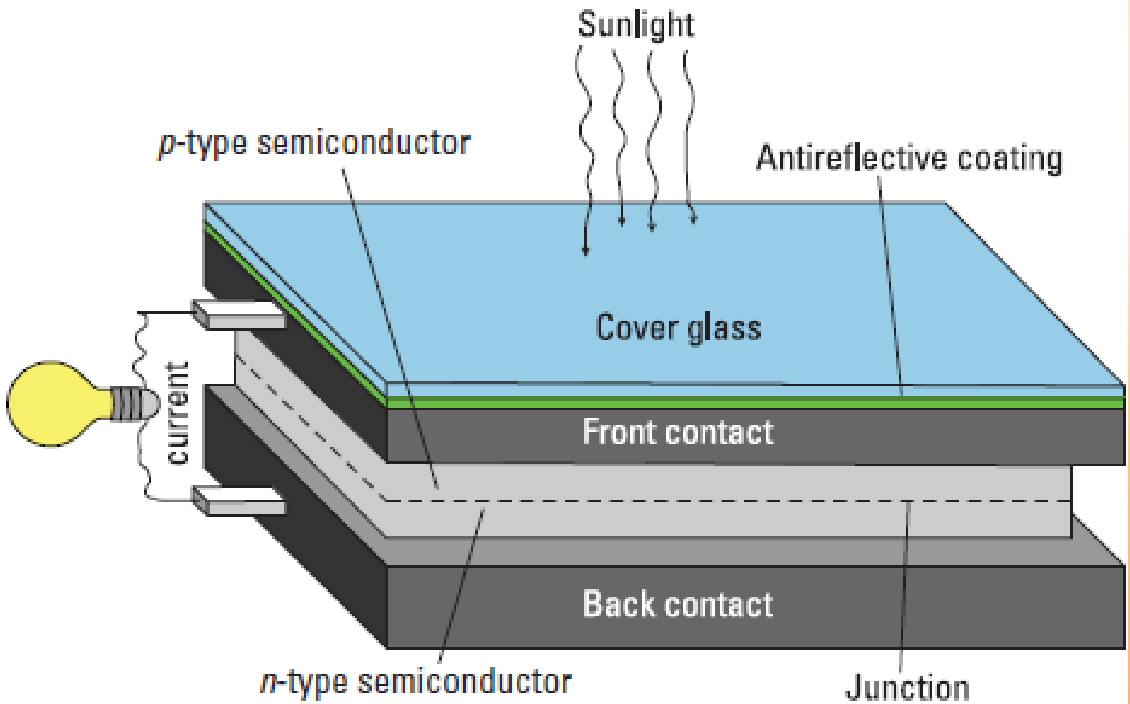


Figure 1. A generalized diagram showing the structure of an electricity-generating solar (photovoltaic) cell. Semiconductor films contain such metals as cadmium, gallium, germanium, indium, selenium, and tellurium. The *p* layer generates a positive charge and the *n* layer generates a negative charge. Front and back contacts made up of conductive metals and alloys containing aluminum, copper, gold, molybdenum, and silver. Diagram courtesy of California Energy Commission, used with permission.

http://pubs.usgs.gov/circ/1365/Circ1365.pdf

Table 2. Metals required[1] to produce thin-film photovoltaic cells with effective annual capacity of 8,760 gigawatthours.

[CIGS, copper-indium-gallium-selenide alloy; e, estimated; XX, not applicable]

Type of photovoltaic technology	Metals required			
	Metal	Quantity[e,2] (metric tons)	Percentage of 2008 estimated world refinery production from primary sources[3]	Value of contained metal[e,4] (in millions of dollars)
Thin-film CIGS	Gallium	30	27	17
	Indium	90	16	62
	Selenium	180	6	13
	Total	XX	XX	92
Thin-film cadmium telluride	Cadmium	340	2	2
	Tellurium	390	82	82
	Total	XX	XX	84

[1]Metals required to produce photovoltaic cells that can generate 4 gigawatts (GW) of peak power or 8,760 gigawatthours per year (GWh/yr) of effective capacity. One GW is equivalent to 1 billion watts, 1,000 megawatts, and 1 million kilowatts of effective capacity of electricity production. Applying a 25 percent capacity factor, an installed peak capacity of approximately 4 GW would be required to produce 1 GW of electricity on an average daily basis or 8,760 GWh/yr, electricity sufficient to meet the average annual need of 11,000 kilowatthours for 800,000 households in the United States (U.S. Department of Energy, Energy Information Administration, 2009a). No energy storage, such as batteries, was assumed.

Tellurium in Photovoltaics

- 9 gm/m^2 & 10% efficiency → 1/10 gm (Te)/W or 100 tonnes (Te)/GW
- ÷ 20 - 25% capacity factor → 400 tonnes (Te)/GW
- World electric consumption (2006) ~2000 GW (USEIA)
- Te "Reserve base" approx. 48,000 tonnes (USGS) → 120 GW

Bottom line — we don't know of enough Te in the world today to make solar as big a contributor to power generation as we would like.

Bismuth telluride heat pump.

This is a small bismuth telluride thermoelectric heat pump. Apply a DC voltage and one side gets cold while the other side gets hot. If you attach a good heat sink and fan to the hot side, you can pump heat out of something, cooling it down. This particular device was deployed inside a USB-powered mini-fridge designed to cool one can of soda using power from your computer.

Source: eBay seller goods_keeper
Contributor: Theodore Gray
Acquired: 28 March, 2009
Text Updated: 29 March, 2009
Price: $6
Size: 1.5"
Purity: <20%

http://periodictable.com/Elements/052/

PRODUCTION

PRODUCTION
(US est 50 tonnes)

Salient Statistics—United States:	2010	2011	2012	2013	2014[e]
Production, refinery	W	W	W	W	W
Imports for consumption, unwrought, waste and scrap	42	71	36	64	68
Exports	59	39	47	42	44
Consumption, apparent	W	W	W	W	W
Price, dollars per kilogram, 99.95% minimum[1]	221	349	150	112	117
Stocks, producer, refined, yearend	W	W	W	W	W
Net import reliance[2] as a percentage of apparent consumption	>60%	<50%	>60%	>80%	>80%

	Refinery production 2013	Refinery production 2014[e]	Reserves[3]
United States	W	W	3,500
Canada	12	10	800
Japan	48	45	—
Peru	—	—	3,600
Russia	35	40	NA
Other countries[4]	NA	NA	16,000
World total (rounded)	NA	NA	24,000

PRODUCTION

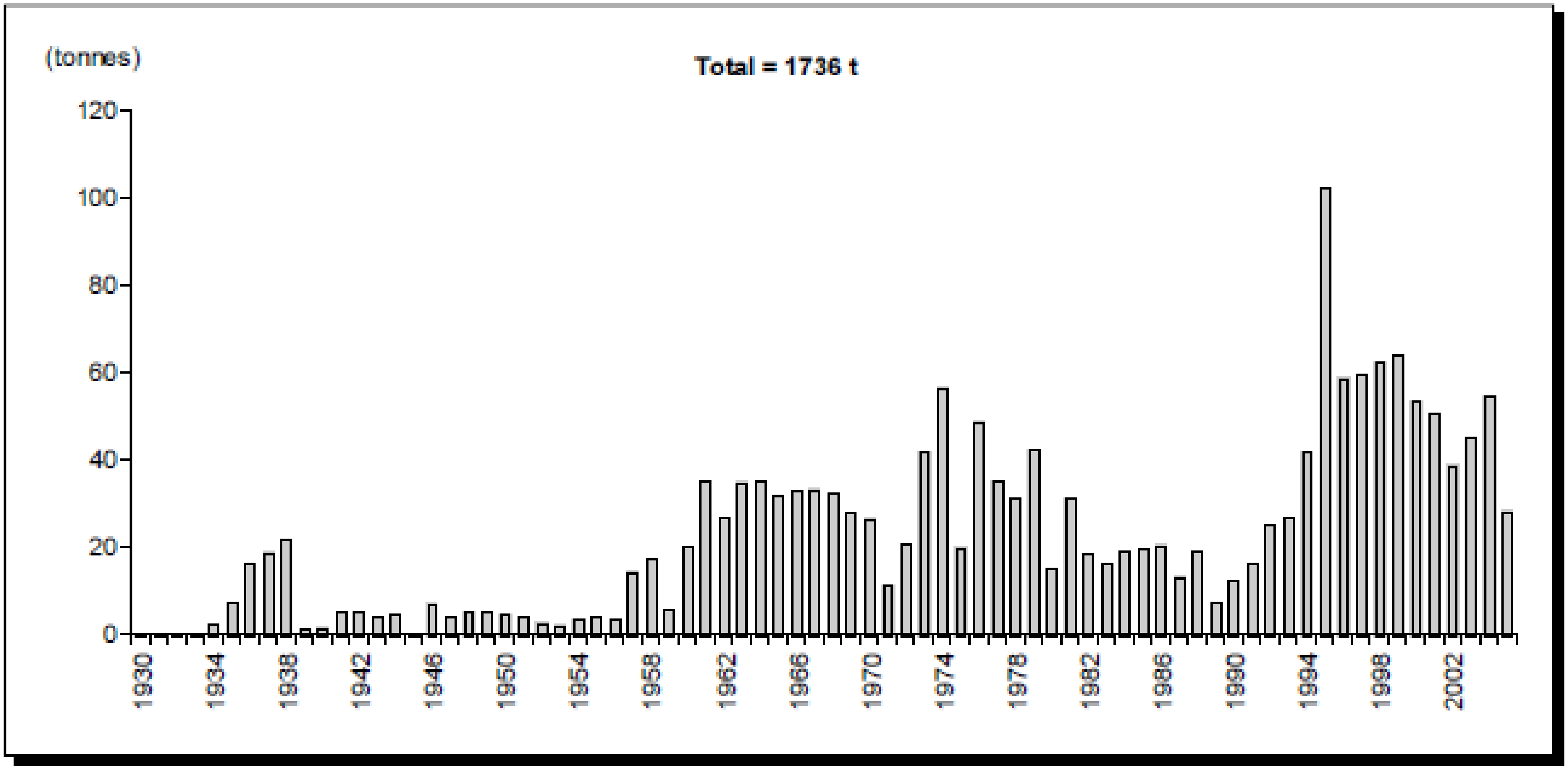
Domestic Production and Use: In 2014, one firm in Texas produced commercial-grade tellurium from domestic copper anode slimes and lead refinery skimmings. Primary and intermediate producers further refined domestic and imported commercial-grade metal and tellurium dioxide, producing high-purity tellurium and tellurium compounds for specialty applications.

World Resources: Data on tellurium resources were not available. More than 90% of tellurium has been produced from anode slimes collected from electrolytic copper refining, and the remainder was derived from skimmings at lead refineries and from flue dusts and gases generated during the smelting of bismuth, copper, and lead-zinc ores. In copper production, tellurium was recovered only during electrolytic refining of smelted copper. Other potential sources of tellurium include bismuth telluride, gold telluride, and lead-zinc ores.

Major sources of Te production

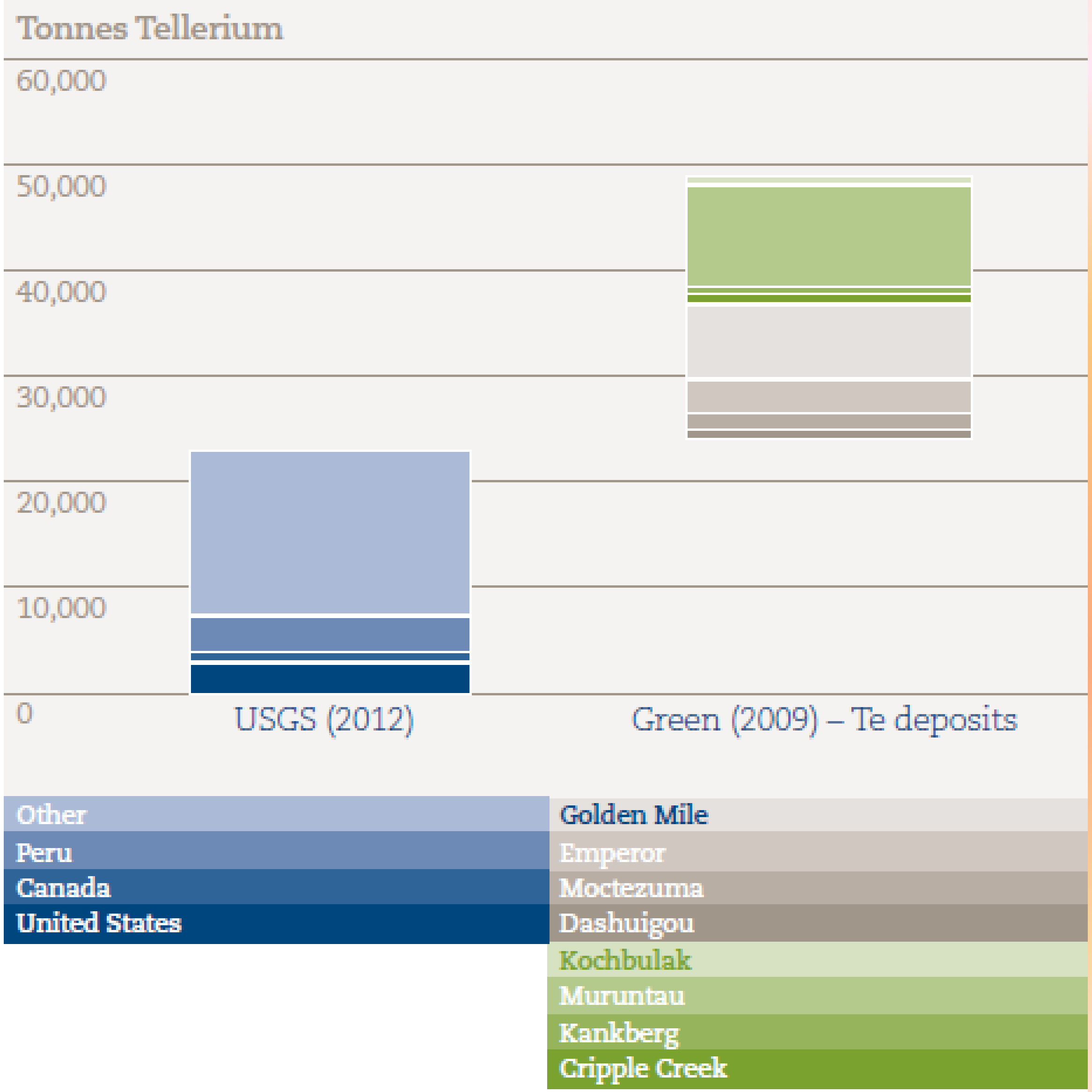
- There is no primary Te mine
- Te is recovered as a byproduct of nonferrous metal mining
  - Copper porphyry deposits
  - Lead and zinc deposits
  - 2% Te in Te-bearing anode slimes (USGS)

Figure 4
Recoverable Tellurium in Concentrates Shipped From Canadian Mines, 1930-2005



Source: Natural Resources Canada.

Tellurium reserves and potential deposits for direct mining



Source: USGS (2012); Green (2009)

Demand

Economics will prevail (e.g., the ratio of the value of global copper production to that of tellurium in 2014 was approximately 2300 to 1, which means metallurgists won't risk lowering copper recovery to improve tellurium recovery).

Country	Reserves Contained Cu Metric Tons	Contained Te Metric Tons	Reserve Base[1] Contained Cu Metric Tons	Contained Te Metric Tons	Total Contained Te Metric Tons
United States	41,000,000	**8,200**	82,000,000	**16,000**	**24,200**
Australia	6,000,000	**1,300**	21,000,000	**4,200**	**5,500**
Canada	10,000,000	**2,000**	21,000,000	**4,200**	**6,200**
Chile	80,000,000	**16,000**	148,000,000	**30,000**	**46,000**
China	3,000,000	**500**	7,000,000	**1,500**	**2,000**
Indonesia	10,000,000	**2,000**	14,000,000	**2,700**	**4,700**
Kazakhstan	13,000,000	**2,500**	18,000,000	**3,600**	**6,100**
Peru	6,000,000	**700**	22,000,000	**2,200**	**2,900**
Philippines	6,000,000	**1,300**	10,000,000	**2,000**	**3,300**
Poland	18,000,000	**3,600**	33,000,000	**6,500**	**10,100**
Russia	18,000,000	**3,600**	27,000,000	**5,400**	**9,000**
Zaire	9,000,000	**1,800**	27,000,000	**5,400**	**7,200**
Zambia	11,000,000	**2,200**	34,000,000	**6,200**	**8,400**
Other Countries	50,000,000	**10,000**	91,000,000	**18,000**	**28,000**
Total	281,000,000	**55,700**	549,000,000	**107,900**	**163,600**

Note: All Figures Rounded

Country	Tons Production Electrolytic Copper	Contained Te (Pounds)	Contained Te Metric Tons	Total Possible Production/Yr. (50% Rec.) M/Tons
United States	1,730,000	548,000	249	124
Australia	490,000	196,000	89	44
Canada	654,700	261,880	118	59
Chile	2,511,000	1,004,400	455	227
China	414,000	165,600	75	37
Bulgaria	100,000	40,000	18	9
Indonesia	529,000	211,648	96	48
Iran	108,000	43,200	20	10
Kazakhstan	316,000	126,400	57	28
Mexico	342,319	136,928	62	31
Mongolia	125,300	50,120	23	11
Paupa New Guinea	111,700	44,680	20	10
Peru	391,265	78,253	35	17
Poland	414,000	165,600	75	37
Portugal	106,500	42,600	19	9
Russia	505,000	202,000	92	46
South Africa	186,000	74,400	34	17
Zambia	287,000	114,800	52	26
TOTAL	**9,321,784**		**1,589**	**795**

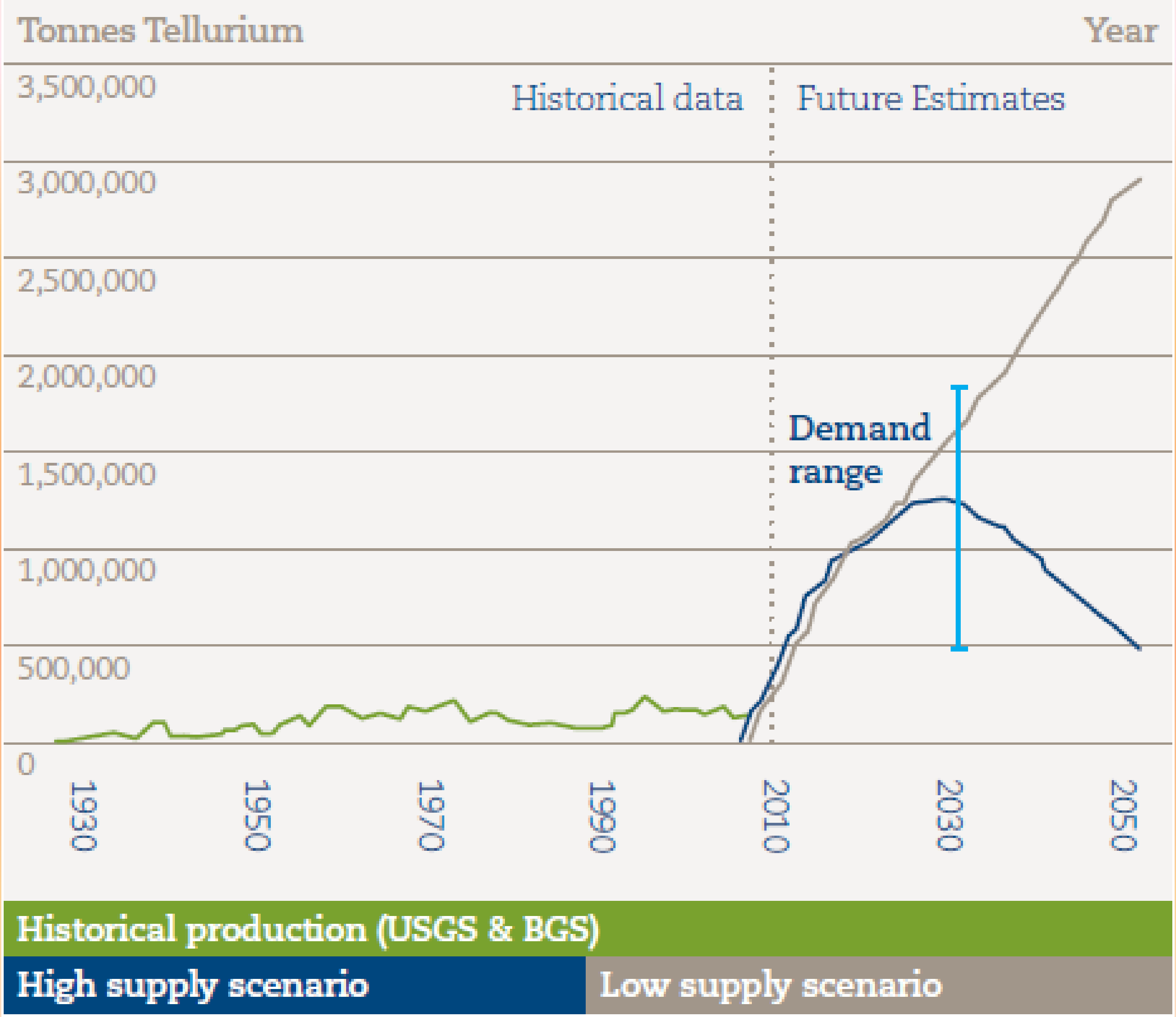
Note: Tellurium tonnage calculations rounded.

Country	Tons Production Refined Lead	Contained Te (Pounds)	Contained Te Metric Tons	Total Possible Production/Yr. (50% Rec.) M/Tons
United States	343,000	34,300	16	8
Australia	204,000	20,400	9	4.5
Belgium	84,400	8,440	4	2
Bulgaria	60,000	6,000	3	1.5
Canada	162,000	16,200	7	3.5
China	506,000	50,600	23	11.5
France	115,000	11,500	5	2.5
Germany	90,000	9,000	4	2
India	69.000	6,900	3	1.5
Italy	115,000	11,500	5	2.5
Japan	142,326	14,233	6	3
Kazakhstan	65,000	6,500	3	1.5
Korea(North)	75,000	7,500	3	1.5
Korea(Republic)	121,296	12,130	6	3
Mexico	168,164	16,816	8	4
Morocco	64,200	6,420	3	1.5
Peru	86,105	8,611	4	2
Poland	50,000	5,000	2	1
Sweden	50,000	5,000	2	1
United Kingdom	215,000	21,524	11	5.5
TOTAL	**2,785,491**		**127**	**64**

Year	Item	Slow	Medium	Fast
			Development Rate	
2000				
	Mw PV Generated Power	1	5	10
	Consumption of Te (Kg/Mw)	130	130	130
	% Manufacturing Loss	40	40	40
	Consumption of Te in Metric Tons	**0.2**	**1**	**2**
2005	Mw PV Generated Power	5	25	100
	Consumption of Te (Kg/Mw)	130	130	130
	% Manufacturing Loss	30	30	30
	Consumption of Te in Metric Tons	**1**	**5**	**19**
2010	Mw PV Generated Power	25	100	1,000
	Consumption of Te (Kg/Mw)	90	90	90
	% Manufacturing Loss	20	20	20
	Consumption of Te in Metric Tons	**3**	**11**	**112**
2020	Mw PV Generated Power	100	500	10,000
	Consumption of Te (Kg/Mw)	90	90	90
	% Manufacturing Loss	10	10	10
	Consumption of Te in Metric Tons	**10**	**50**	**1,000**
2030	Mw Pv Generated Power	500	2,000	30,000
	Consumption of Te (Kg/Mw)	90	90	90
	% Manufacturing Loss	10	10	10
	Consumption of Te in Metric Tons	**50**	**200**	**3,000**

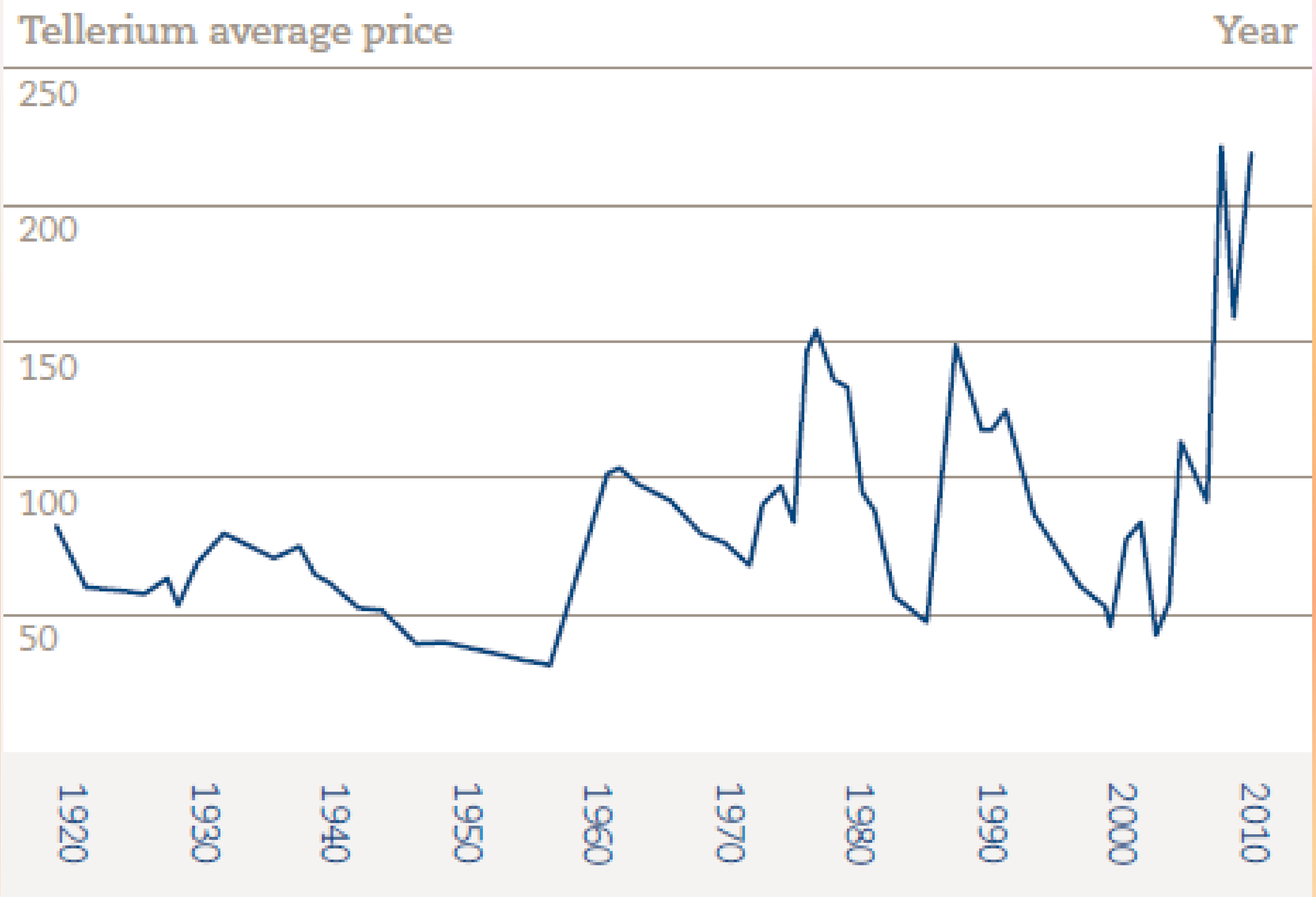
Note: Tellurium Tonnage calculations rounded

Tellurium: Historical production forecast supply and future demand



Source: USGS (2012); Speirs et al (2011)

Tellerium average yearly price



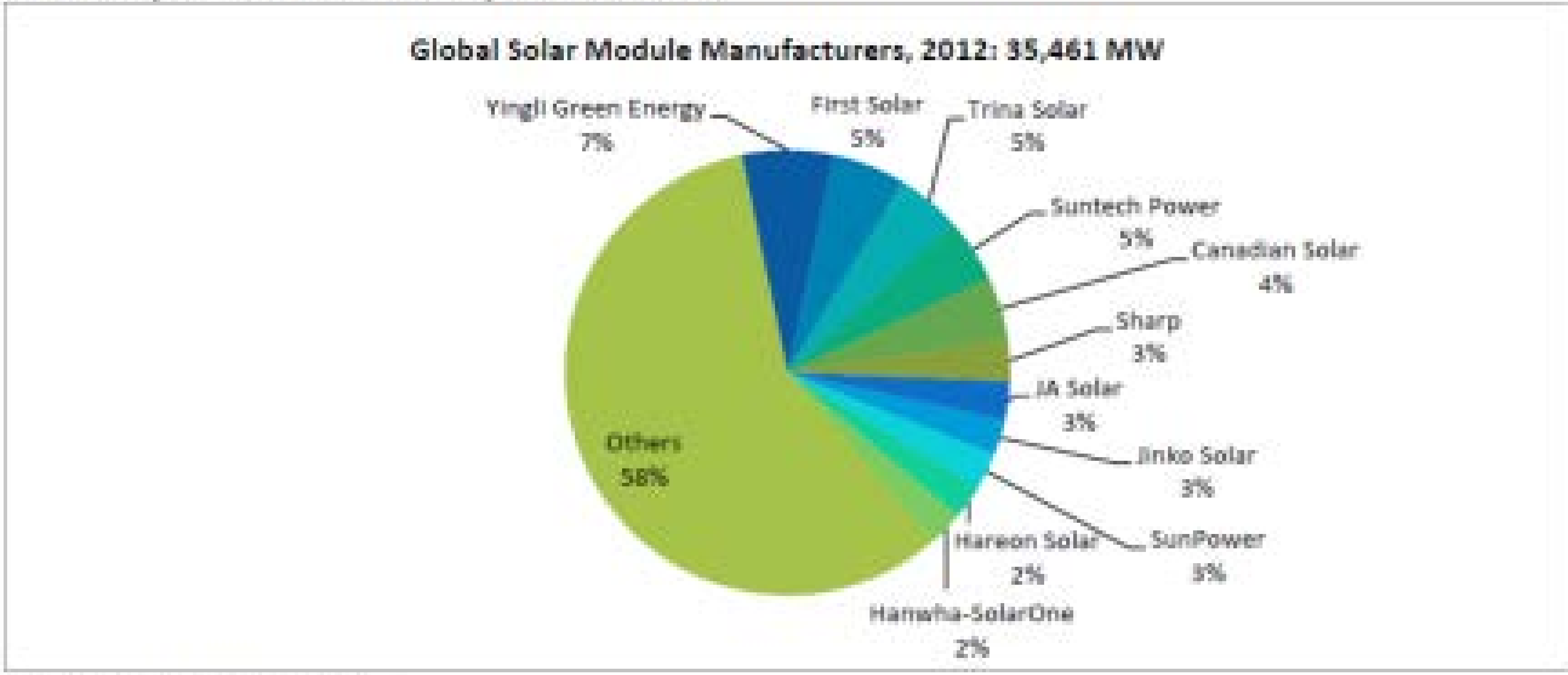
Source: USGS (2011)

Solar energy metals requirements

Technology	Elements	Annual EU Demand (tonnes)		Annual EU Demand / World Supply	
		2020	2030	2020	2030
Solar PV	Te	150	126	12.0%	6.9%
	In	145	121	7.6%	4.9%
	Sn	14,913	12,505	3.6%	2.6%
	Ag	619	519	1.7%	1.2%
	Ga	4	3	0.8%	0.5%
	Se	15	13	0.4%	0.3%
	Cd	109	91	0.3%	0.2%
	Cu	70,650	59,241	0.3%	0.2%
	Pb	8,672	7,272	0.1%	<0.1%

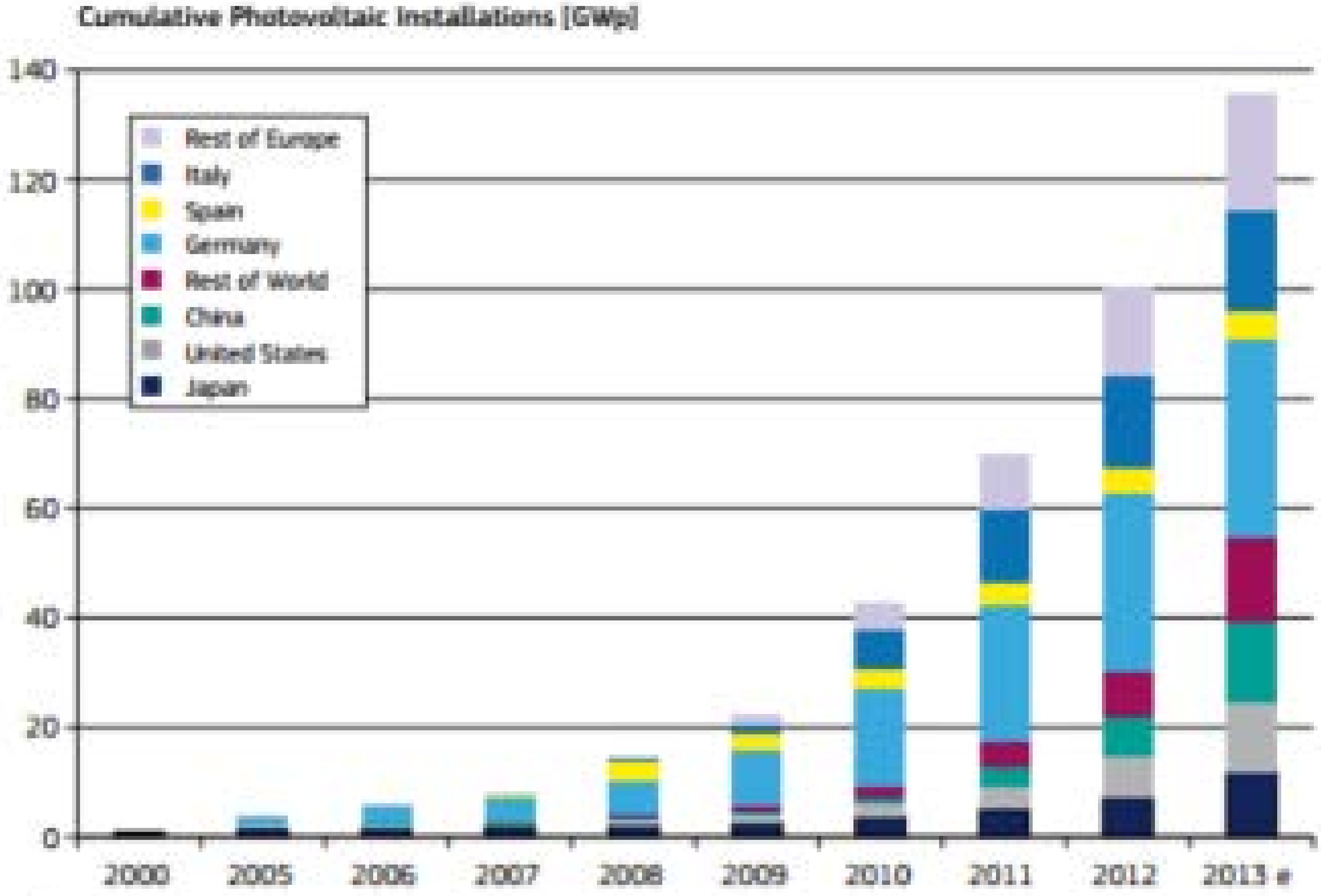
EC JRC/SETIS (2013), Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector

Global major solar module manufacturers, 2012



Source: GTM PV News, May 2013

Cumulative photovoltaic installations from 2000 to 2013 (GWp)



EC JRC/SETIS (2013), 2013 PV status report pg 12

Demand

- Currently 300 metric tons of Te per year are required
- By 2020 1,000 metric tons and non PV Te demand is estimated to be 600 metric tons
- By 2020 new sources of Te will have to be developed in order to meet any increasing demand by the PV industry

Mineralogy

Major Te minerals

- calaverite $AuTe_2$
- krennerite $(AuAg)Te_2$
- petzite Ag_3AuTe_2
- sylvanite $AgAuTe_4$
- hessite (Ag_2Te)
- tellurobismuthite $(BiTe_3)$
- tetradymite (Bi_2Te_2S)
- altaite (PbTe)

- native metal
- 40 minerals
- many of which are telluride minerals
- Few elements to bond with native Au
- Coal—2 ppm Te

Sylvanite, $AgAuTe_4$, Pyrite from Silver City, New Mexico

http://www.johnbetts-fineminerals.com/jhbnyc/mineralmuseum/picshow.php?id=20437

Altaite, $PbTe$, Hilltop Mine, Organ District, Dona Ana County, NM

http://www.johnbetts-fineminerals.com/jhbnyc/mineralmuseum/picshow.php?id=20437

TYPES OF TELLURIUM DEPOSITS

Te associated

- Any age
- Alkaline rocks
- Porphyry deposits
- Bismuth deposits
- Pyrrhotite-chalocpyrite-pentlandite-telluride deposits
- Palladium in PGM deposits

TYPES OF TELLURIUM DEPOSITS

- Au-Ag-Te alkaline-related veins
- Volcanic-epithermal veins
- Skarns/carbonate-hosted deposits
- Polymetallic veins
- Vein and replacement deposits in Proterozoic rocks
- Porphyry copper (±molybdenum, gold) deposits
- Polymetallic gold deposits
- Gold quartz-pebble conglomerate deposits
- Carlin-type deposits
- Lead-zinc ores
- Black shale hosted deposits
- Coal

Type of deposit	Te (ppm)
Gold-quartz veins	0.2-2,200
Gold skarn deposits	0.2-0.5
Polymetallic gold deposits	0.2-10
Gold quartz-pebble conglomerate deposits	<0.2-0.7
Carlin-type deposits	<0.2-0.6
Porphyry copper deposits	<0.1-6,000
Lead-zinc ores	0.5-1.0

Ranges in concentration of tellurium in selected deposits (Everett, 1964; Boyle, 1979; Cox et al., 1995).

Deposit/Region	Tellurium Concentration Pounds Per Refined Ton Of Metal
U.S. Porphyry Copper Deposits	0.4
Sudbury Canada Massive Sulfide Deposits	0.06
World Wide Lead Ore Deposits	0.1
Peru Porphyry Copper Deposits	0.2
Chile Porphyry Copper Deposits	0.4
Congo Copper Deposits	0.4
Zambia Copper Deposits	0.4
Russian/CIS Copper Nickel-Copper, Massive Sulfide Deposits	0.4
Mexican Copper and Massive Sulfide Deposits	0.4
Australia/New Guinea Copper Deposits	0.4
Japan/Philippines/Chinese Copper and Massive Sulfide Deposits	0.4
European Copper and Massive Sulfide Deposits	0.4

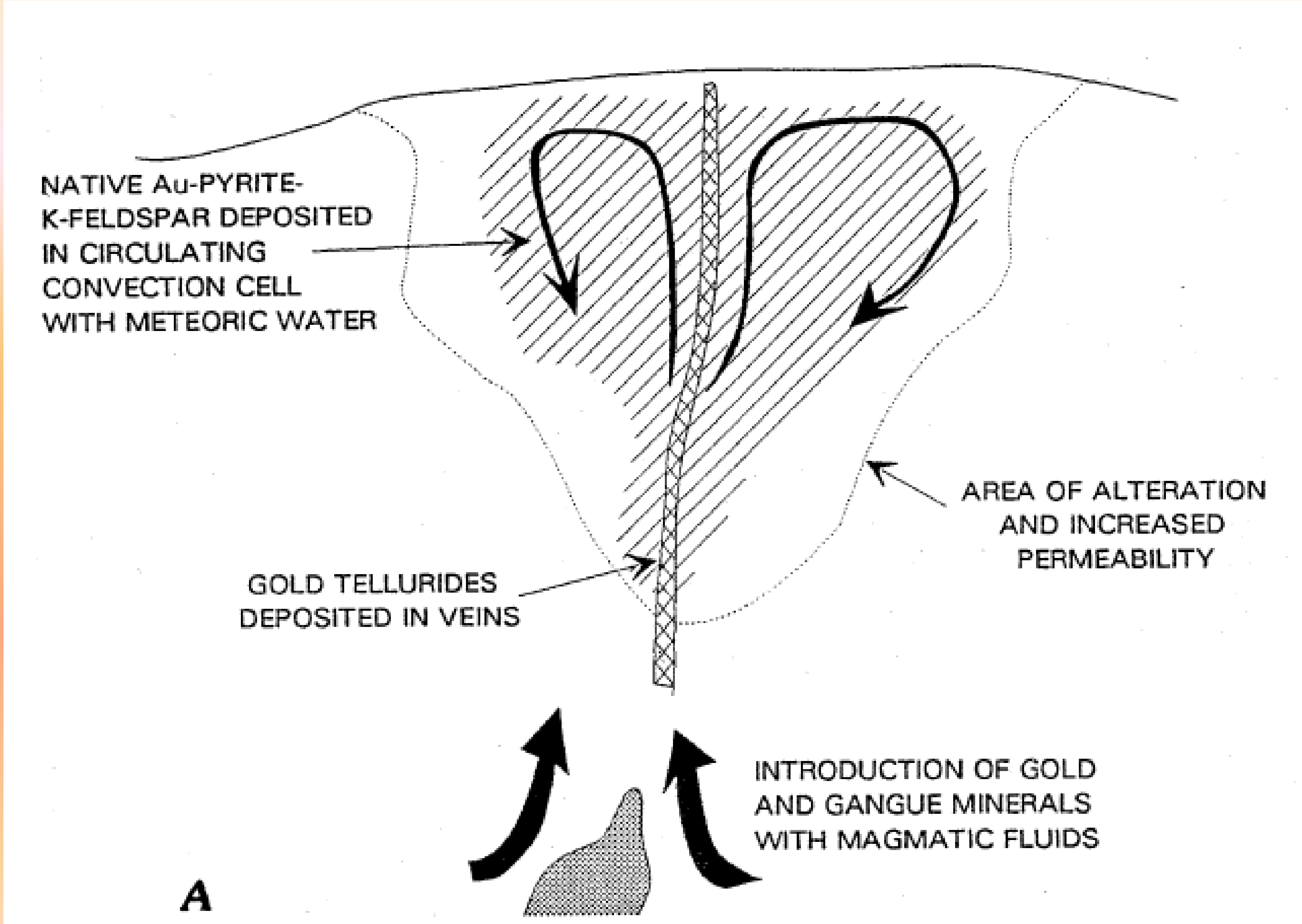
Au-Ag-Te alkaline-related veins

Table 1 Traditional gold and copper deposit types related to alkaline rocks

Deposit type	Example	Metals	Related alkaline rocks	Selected reference
Porphyry Cu–Au	Cadia, NSW, Australia	Au–Cu	Monzodiorite-quartz monzonite porphyry stock	Holliday et al. (2001), this volume
Skarn	Lukas Canyon, New Mexico	Au–Cu	Monzonite and latite porphyry stocks	Maynard et al. (1990)
Sediment-hosted (Carlin-style)	Foley Ridge and Annie Creek, South Dakota	Au	Monzonite porphyry, quartz monzonite porphyry and phonolite dykes and sills	Lessard and Loomis (1990)
Breccia pipe	Golden Sunlight, Montana	Au	Latite porphyry intrusions	Spry et al. (1996)
Low-sulphidation epithermal vein	Emperor, Fiji	Au	Absarokite-shoshonite shield volcano and monzonite stocks	Eaton and Setterfield (1993)
Pluton-related (mesothermal or orogenic) vein	Dongpin, China	Au	Syenite pluton, latite porphyry and lamprophyre dykes	Zhang and Mao (1985)
Volcanogenic massive sulphide (VMS)	Rea, British Columbia	Cu–Zn–Pb–Ag–Au	Alkaline basalt tuffs	Höy (1991)

Au-Ag-Te alkaline-related veins

- Cripple Creek
- Zortman-Landusky
- Golden Sunlight
- White Oaks and Ortiz



http://pubs.usgs.gov/of/1995/ofr-95-0831/CHAP15.pdf

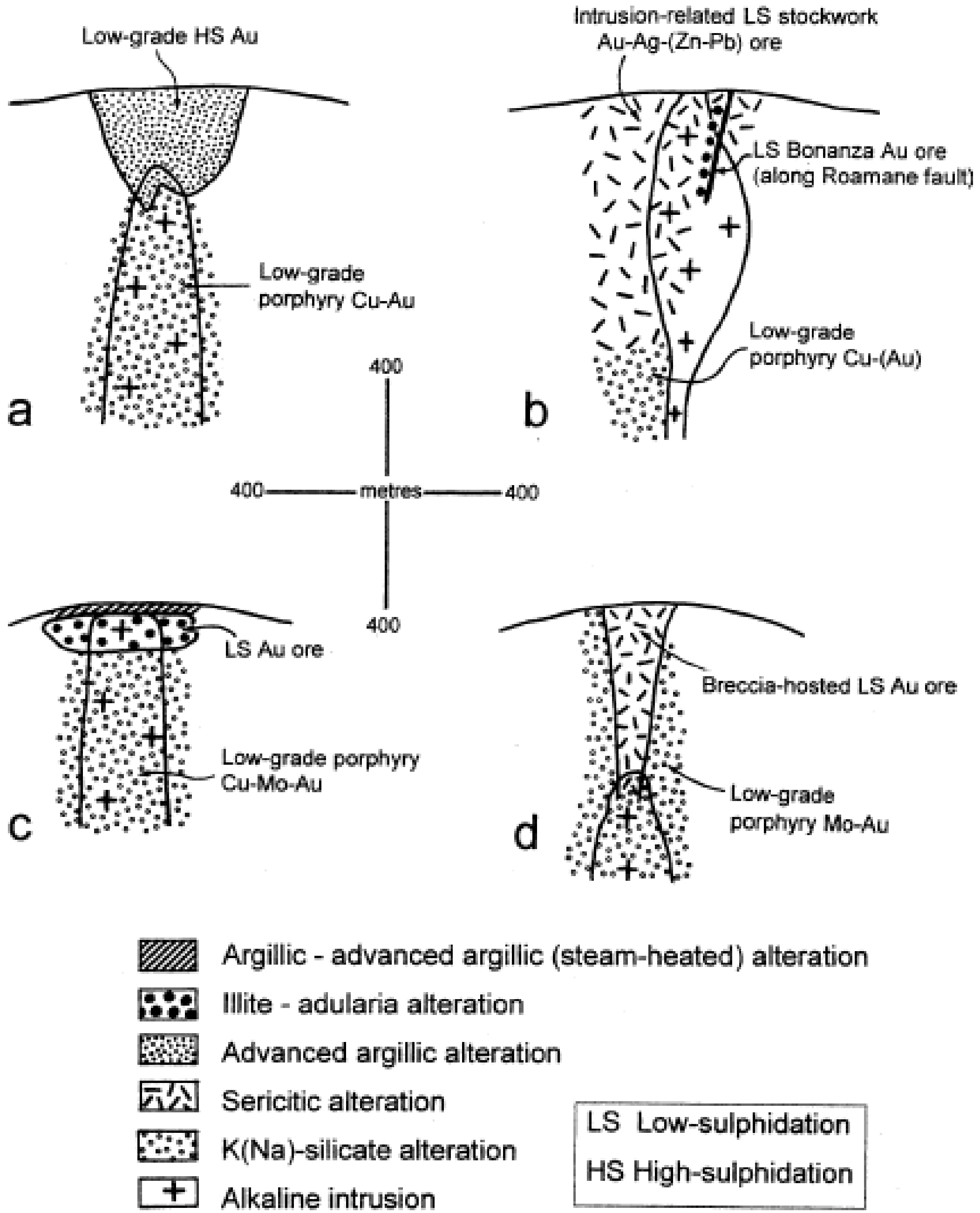


Fig. 1a–d Cartoons to show the generalised nature of the porphyry-epithermal transition in four gold ± copper systems related to alkaline rocks. **a** Navisi 3, Fiji (inspired by Eaton and Setterfield 1993). **b** Porgera, Papua New Guinea (inspired by Richards and Kerrich 1993, and Ronacher et al. 1999). **c** Ladolam, Papua New Guinea (inspired by Moyle et al. 1990). **d** Golden Sunlight, Montana, United States (inspired by Spry et al. 1996; personal observations, 1980). Existence of the high-sulphidation epithermal environment at Navisi 3 is unusual in alkaline igneous centres, which appear to be typified by low-sulphidation epithermal mineralisation above or overprinting the porphyry environment

Au-Ag-Te alkaline-related veins

- calaverite and sylvanite
  - Au:Te ratio is 1:1
- petzite and krennerite
  - Au:Te ratio is 2:1
- Emperor mine (Fiji) the Au-Te is 10 ppm for Au and 10 ppm for Te
- Bambola ore deposit, the Au-Te is 1:176
- Lone Pine ore deposit (NM), the ratio of Au (4.5 ppm) to Te (4500 ppm) becomes 1:1000

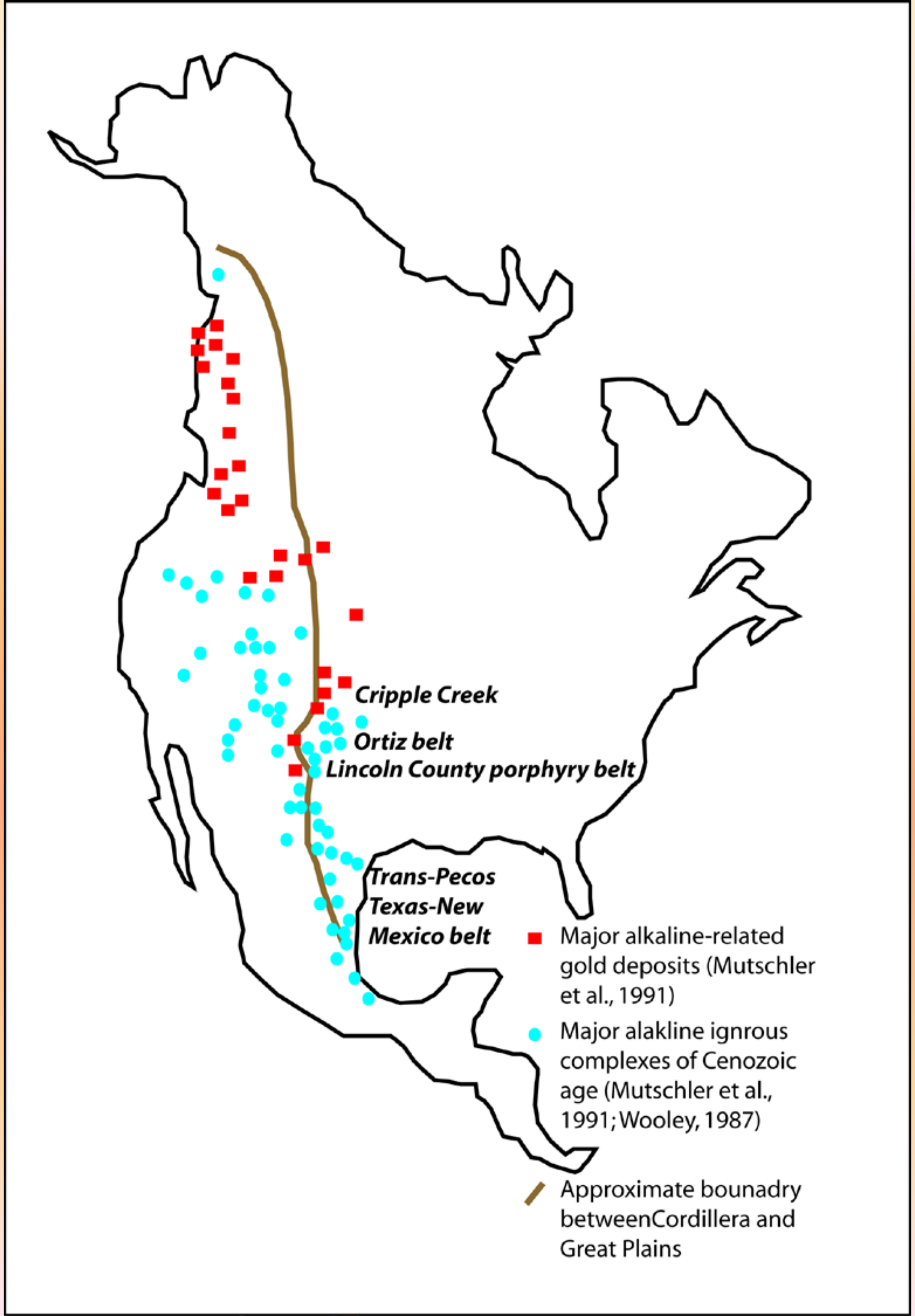
Table 1: Representative Au-Te deposits. Supplementary data from Jensen and Barton (2000); Sillitoe (2002)

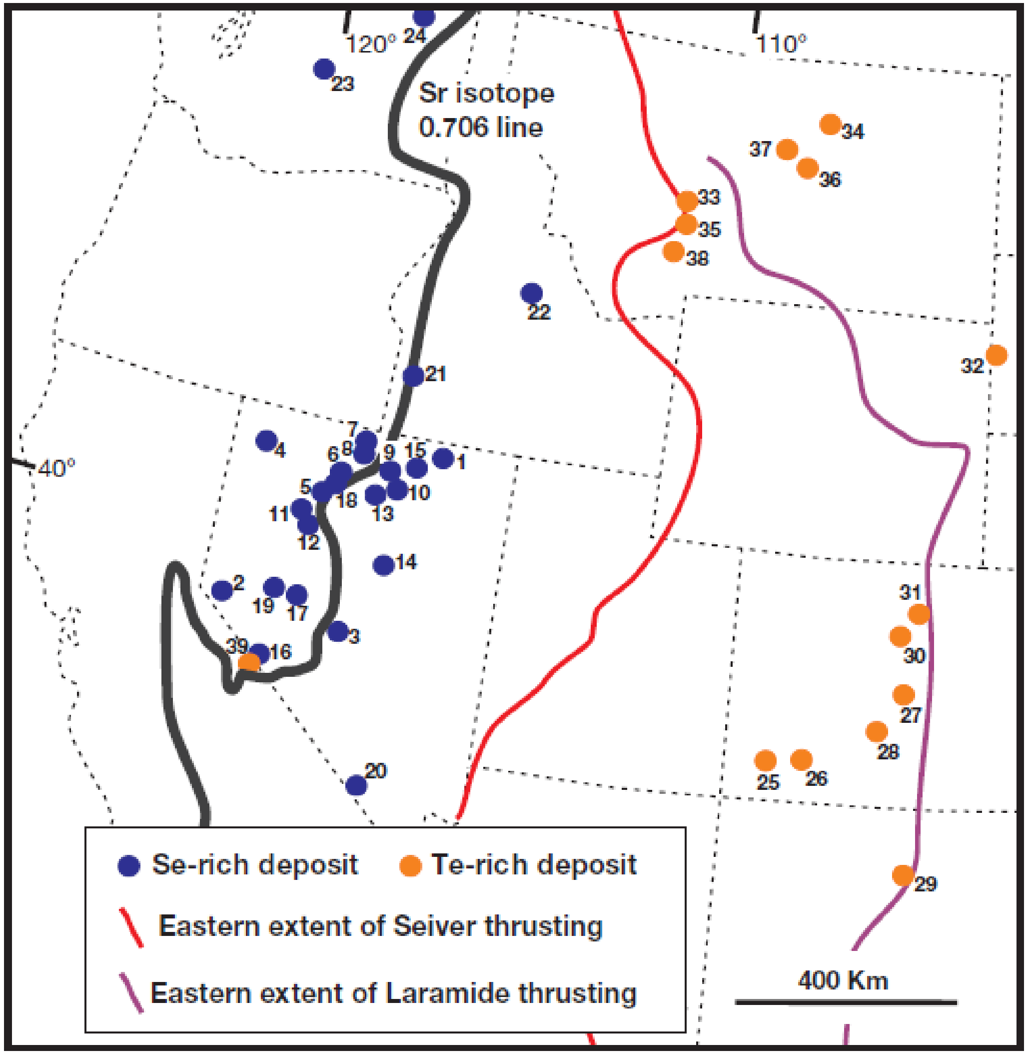
Deposit	Province	Type	Tellurides			Au (t)	Age (Ma)	Reference(s)
			Au-Ag	Bi	Others			
Golden Mile, Kalgoorlie, Western Australia	Yilgarn Craton	Transitional epi-mesozonal	X		X	1,457	2675-2660	Hagemann & Cassidy 2000; Shackleton et al. 2003
Cripple Creek, CO, USA	Colorado alk. prov.	Epithermal LS	X			834	31-28	Kelley et al. 1998
Golden Sunlight, MT, USA	Montana alk. prov.	Epithermal LS	X			112	70-80	Spry et al. 1997
Emperor, Fiji	Pacific Rim	Epithermal LS	X		X	120	5-4	Pals & Spry 2003
Porgera, Papua New Guinea	Pacific Rim	Epithermal LS	X			660	6	Richards & Kerrich 1993
Ladolam, Papua New Guinea	Pacific Rim	Epithermal LS	X			1,190	<1	Müller et al. 2002
Acupan, Baguio, Philippines	Pacific Rim	Epithermal LS	X			200+	0.6	Cooke & McPhail 2001
Sacarîmb, Romania	'GQ', Apuseni Mts.	Epithermal LS	X		X	32	12-10	Ciobanu et al. 2004a
Kochbulak, Uzbekistan	Kurama Belt, Middle Tien Shan	Epithermal LS/HS	X	X	X	33.5	280-270	Kovalenker et al. 1997

Table 2 Aberrant gold and copper deposits related to alkaline rocks

Deposit	Metal content	Related alkaline rocks	Age (Ma)	Tectonic setting	Selected reference
Cripple Creek, Colorado	834 t Au	Phonotite to alkali basalt (lamprophyre) diatreme complex	31–28	Extensional back arc, preparatory to Rio Grande intracontinental rift	Kelley et al. (1998)
Ladolam, New Papua Guinea	1,190 t Au	Trachyandesite-latite stratovolcano, monzodiorite stocks	< 1	Post-subduction extension	Moyle et al. (1990)
Porgera, Papua New Gunea	660 t Au	Minor alkaline gabbro and mafic porphyry stocks	6	Fold-thrust belt linked to continent-island arc collision	Richards and Kerrich (1993)
Olympic Dam, Australia	20 Mt Cu, 1,200 t Au, 1 Mt U	Syenogranite pluton, felsic and alkaline mafic-ultramafic dykes	~1590	Intracontinental rift	Reeve et al. (1990)
Phalaborwa, South Africa	4.25 Mt Cu + Au	Foskorite and carbonatite intrusions	~2060	Intracontinental extension	Verwoerd (1986)
Zortman-Landusky, Montana	120 t Au	Quartz monzonite and syenite phases of laccolith, tinguaite dykes	~62	Extensional back-arc above flat slab	Russell (1991)

North American Alkaline Gold Belt


Cripple Creek
Ortiz belt
Lincoln County porphyry belt
Trans-Pecos
Texas-New
Mexico belt
Major alkaline-related gold deposits (Mutschler et al., 1991)
Major alakline ignrous complexes of Cenozoic age (Mutschler et al., 1991; Wooley, 1987)
Approximate bounadry betweenCordillera and Great Plains

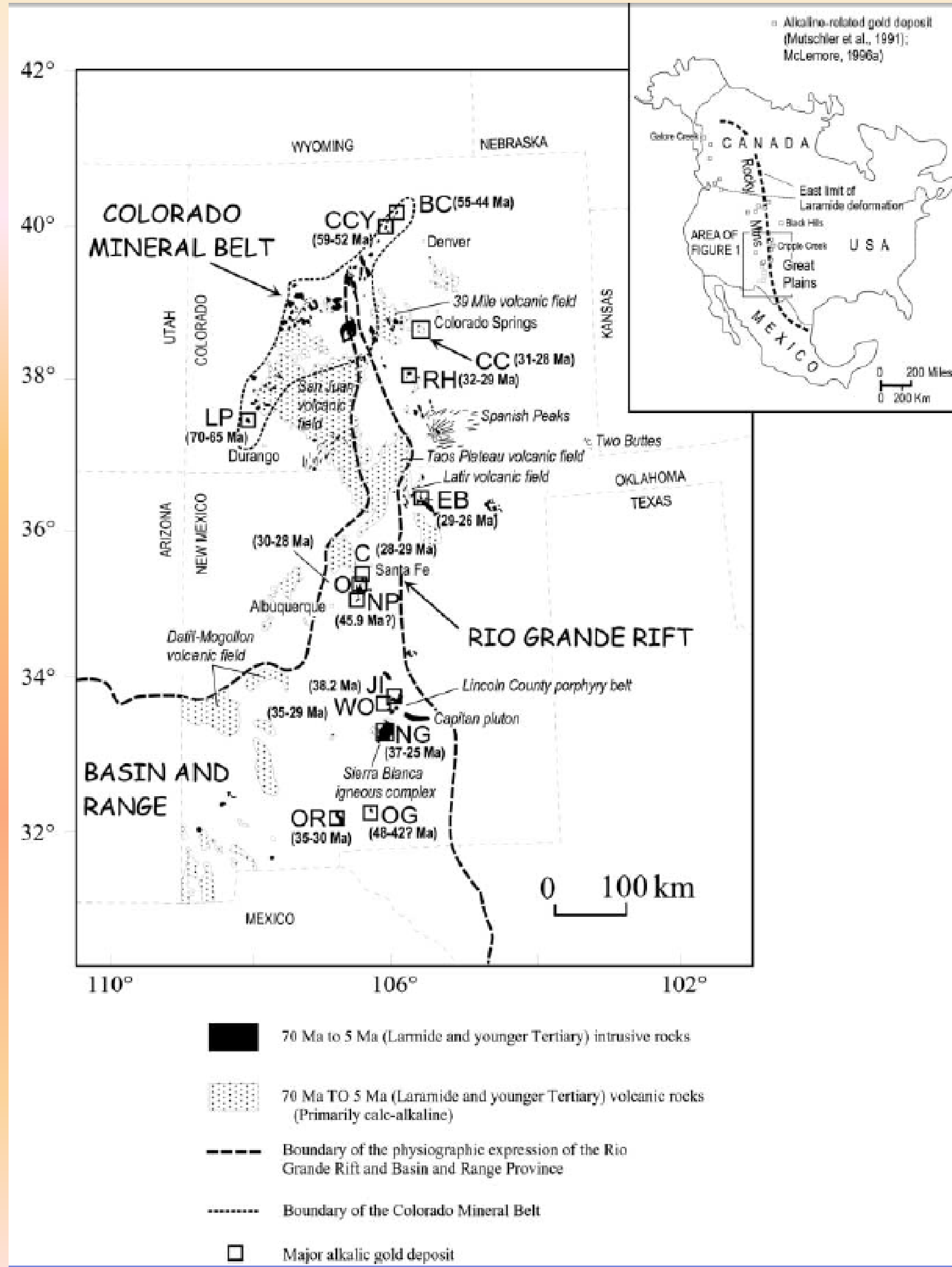


hypothesis that Laramide subduction prepared the mantle underlying the western United States for subsequent ore genesis

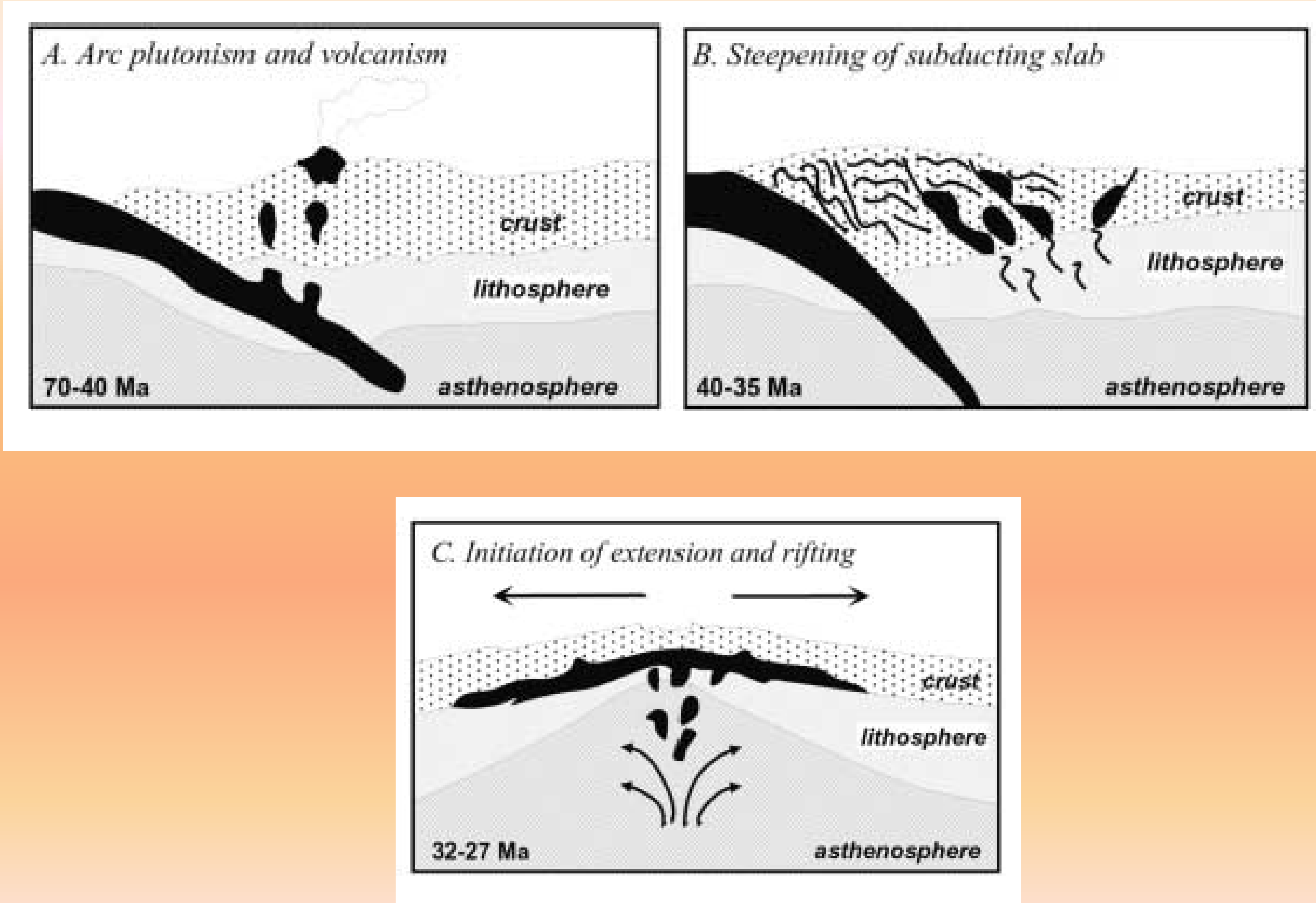
devolatilization reactions in a subducted slab can cause the overlying mantle to be enriched in volatile ore-forming constituents

FIG. 2. Map showing localities of Laramide and younger epithermal ores of the western United States where data on Te and Se exists. See Table 1 for deposit names, data sources.

Saunders and Brueseke, 2012, Econ Geol

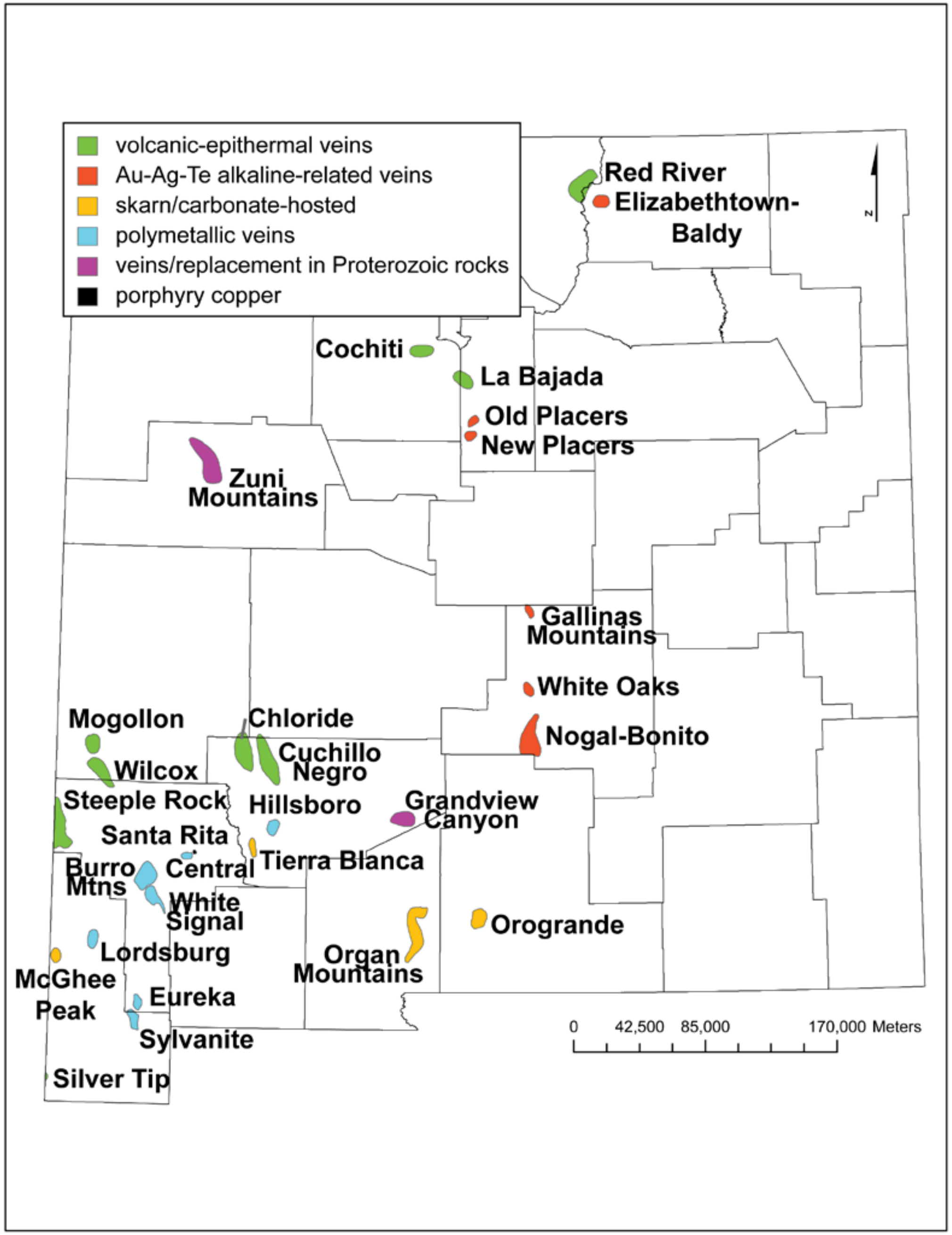


COLORADO MINERAL BELT
WYOMING
NEBRASKA
UTAH
COLORADO
KANSAS
ARIZONA
NEW MEXICO
OKLAHOMA
TEXAS
MEXICO
BC (55-44 Ma)
CCY (59-52 Ma)
Denver
39 Mile volcanic field
Colorado Springs
CC (31-28 Ma)
RH (32-29 Ma)
San Juan volcanic field
Spanish Peaks
LP (70-65 Ma)
Durango
Two Buttes
Taos Plateau volcanic field
Latir volcanic field
EB (29-26 Ma)
(30-28 Ma)
C (28-29 Ma)
Santa Fe
O
NP (45.9 Ma?)
Albuquerque
RIO GRANDE RIFT
Datil-Mogollon volcanic field
(38.2 Ma) JI
Lincoln County porphyry belt
(35-29 Ma) WO
Capitan pluton
NG (37-25 Ma)
Sierra Blanca igneous complex
BASIN AND RANGE
OR (35-30 Ma)
OG (46-42? Ma)
0 100 km
42°
40°
38°
36°
34°
32°
110°
106°
102°
Alkaline-related gold deposit (Mutschler et al., 1991); McLemore, 1996a)
CANADA
USA
MEXICO
Rocky Mtns.
East limit of Laramide deformation
Black Hills
Cripple Creek
Great Plains
AREA OF FIGURE 1
0 200 Miles
0 200 Km
70 Ma to 5 Ma (Larmide and younger Tertiary) intrusive rocks
70 Ma TO 5 Ma (Laramide and younger Tertiary) volcanic rocks (Primarily calc-alkaline)
Boundary of the physiographic expression of the Rio Grande Rift and Basin and Range Province
Boundary of the Colorado Mineral Belt
Major alkalic gold deposit


A. Arc plutonism and volcanism
crust
lithosphere
70-40 Ma
asthenosphere
B. Steepening of subducting slab
crust
lithosphere
40-35 Ma
asthenosphere
C. Initiation of extension and rifting
crust
lithosphere
32-27 Ma
asthenosphere

New Mexico Deposits

- Elizabethtown-Baldy district
  - 471,400 oz Au produced
- Old Placers district
  - 450,000 oz produced
- New Placers district
- Jicarilla district
- White Oakes district
- Nogal-Bonito district
- Orogrande district
  - 305,000 metric tons of ore grading 1.7 ppm Au
- Great Western deposit – 3.275 million metric tons of ore containing less than 2 ppm Au
- Vera Cruz deposit – 188,590 metric tons of ore grading 4.8 ppm Au
- Carache Canyon breccia deposit—4.5 million metric tons of ore grading 3.2 ppm Au
- Lukas Canyon—5.4 million metric tons of ore grading 1 ppm Au



Mining districts in New Mexico with tellurium minerals or chemical assays >20 ppm Te

Te in NM deposits

- Laughlin Peak-Chico Hills—210 ppm Te (Schreiner, 1991)
- Mudpuppy-Waterdog deposit—7.1 ppm Te
- Te minerals reported in Elizabethtown-Baldy

Types of deposits

- polymetallic epithermal to mesothermal veins
- gold-bearing breccia deposits and quartz veins
- copper-gold and/or gold porphyries
- iron skarns and replacements
- copper, lead-zinc, and gold skarns or carbonate-hosted replacements
- gold placers
- Th-U-REE-fluorite epithermal veins and breccias

Polymetallic epithermal to mesothermal veins

- thin, less than a meter wide, have steep dips, and occur along faults
- weak propylitic to argillic
- Ag/Au ratios less than 5
- Te spotty, with pyrite and gold

Gold-bearing breccia deposits and quartz veins

- Breccia deposits occur as pipes or conical bodies and vary in size
  - Vera Cruz deposit is approximately 200 m long and 60 m wide
  - Cunningham Hill deposit was approximately 210 m long and 120 m wide
- Quartz, pyrite, electrum, and native gold with little or no additional sulfides
- Breccia fragments are typically highly altered and vary in size
- multiple banding, hydrothermal brecciation, bladed calcite and/or quartz, vuggy textures, and druzzy quartz
- Te unknown but reported

Copper-gold and/or gold porphyries

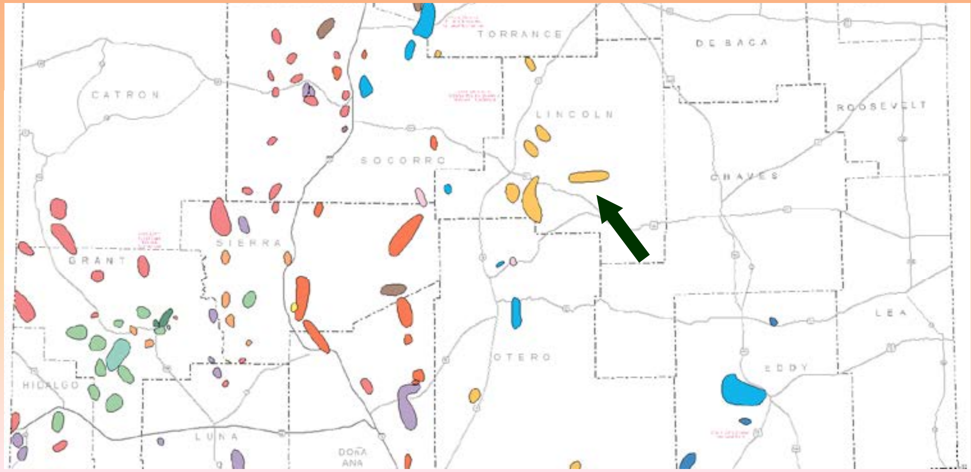
- Cu minerals and locally Au and Mo occur as disseminations and stockwork veinlets
- Mudpuppy-Waterdog– zoned outer propylitic to argillic to inner phyllic alteration to a core of silicified and oxidized breccia
- Ag/Au ratios >1
- Te???

Iron skarns and replacements

- Capitan, contained >1 million tons of Fe ore grading 45.64% Fe
- hematite and magnetite
- lenses or irregular bodies in limestone and as veins filling fractures, faults, and along bedding planes
- Te??

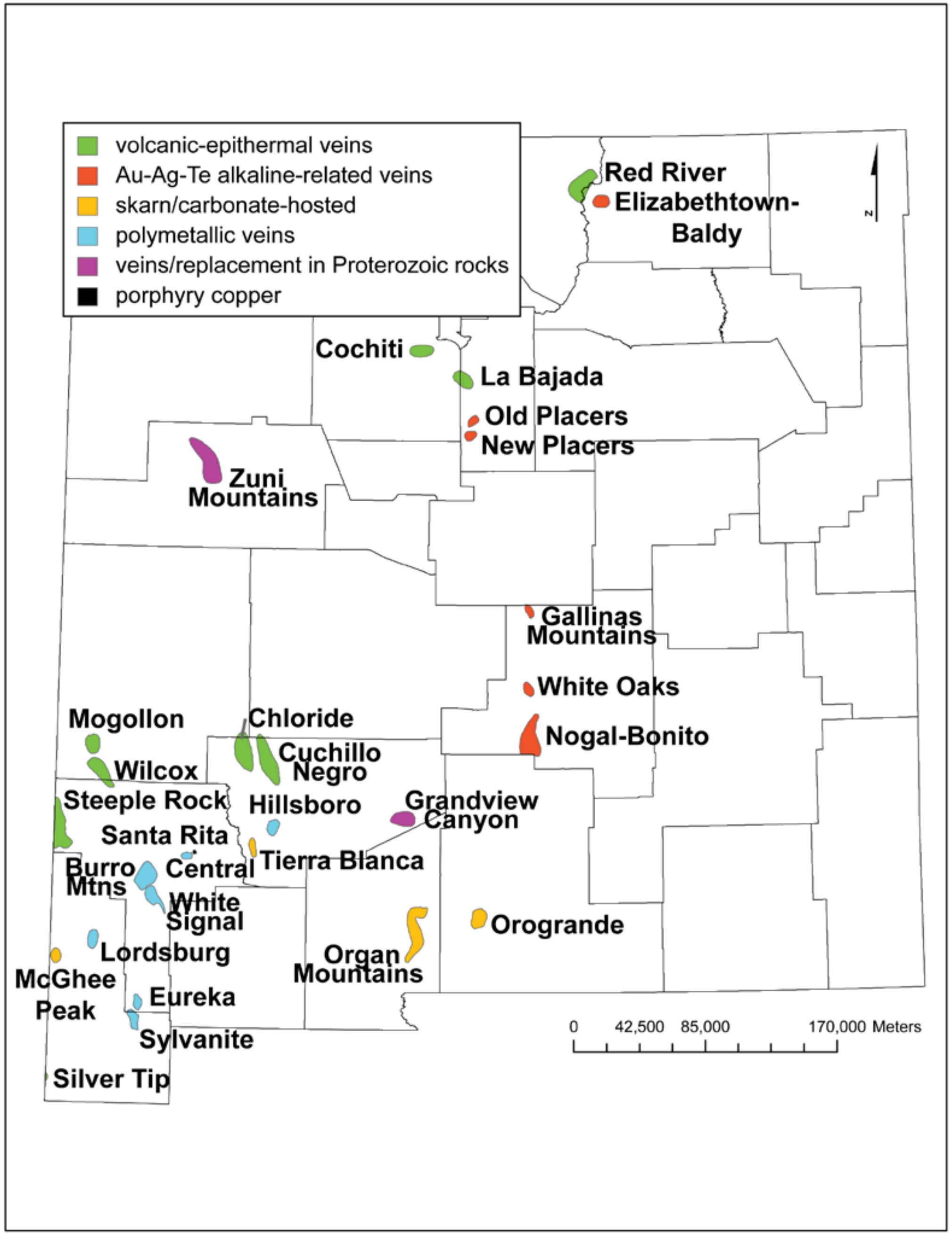
Iron ore from the Capitan Mts

- Produced 250,000 mill tons Fe ore 1963-1988
- El Capitan Precious Metals Corp. claims a resource of 141,000 tons ore of 0.041 oz/t Au
- Drilling permit approved by MMD 11/26/07, but rejected by the USFS requesting additional work



Copper, lead-zinc, and gold skarns or carbonate-hosted replacements

Organ Mountains, Doña Ana County—carbonate-hosted Pb-Zn



Mining districts in New Mexico with tellurium minerals or chemical assays >20 ppm Te

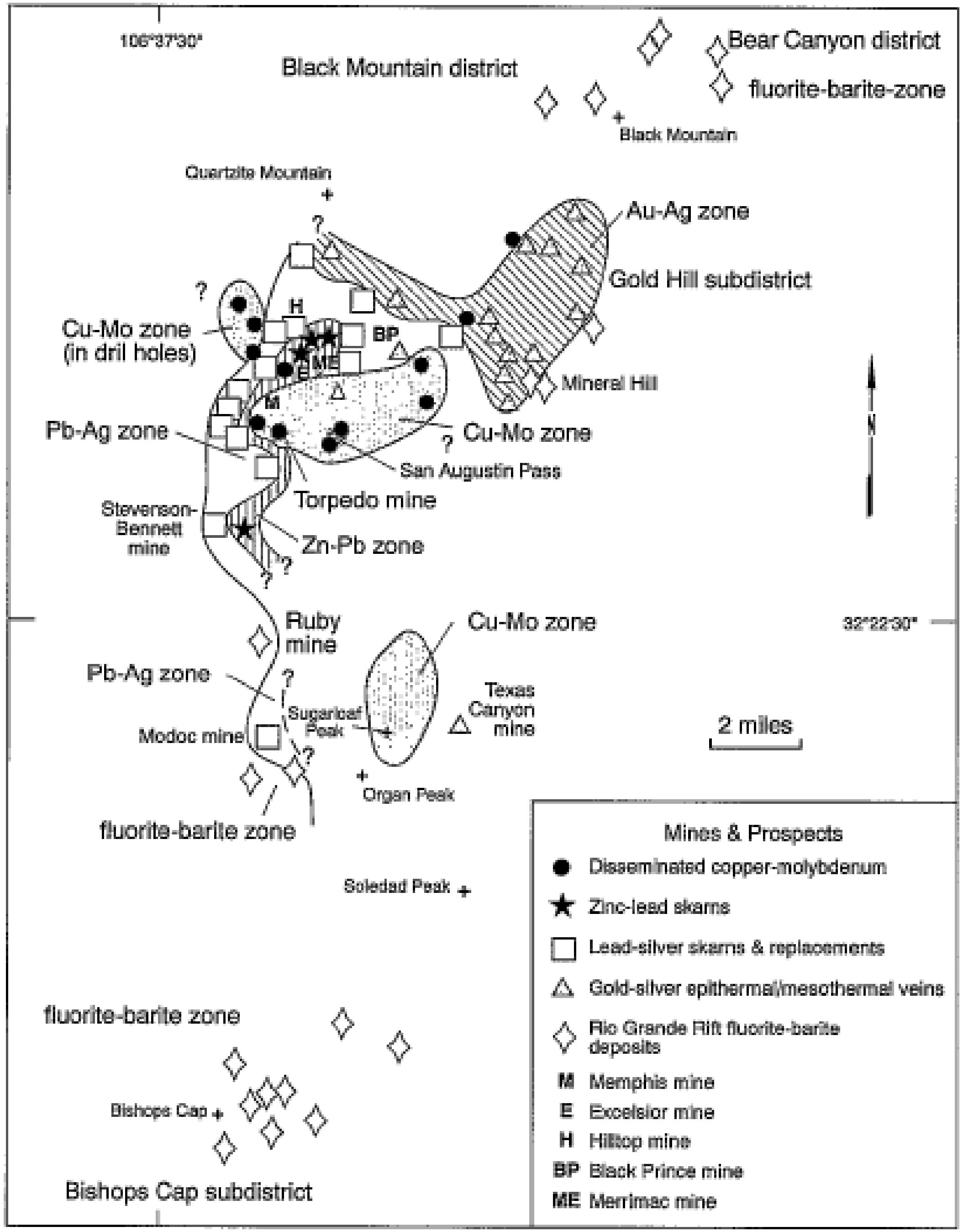
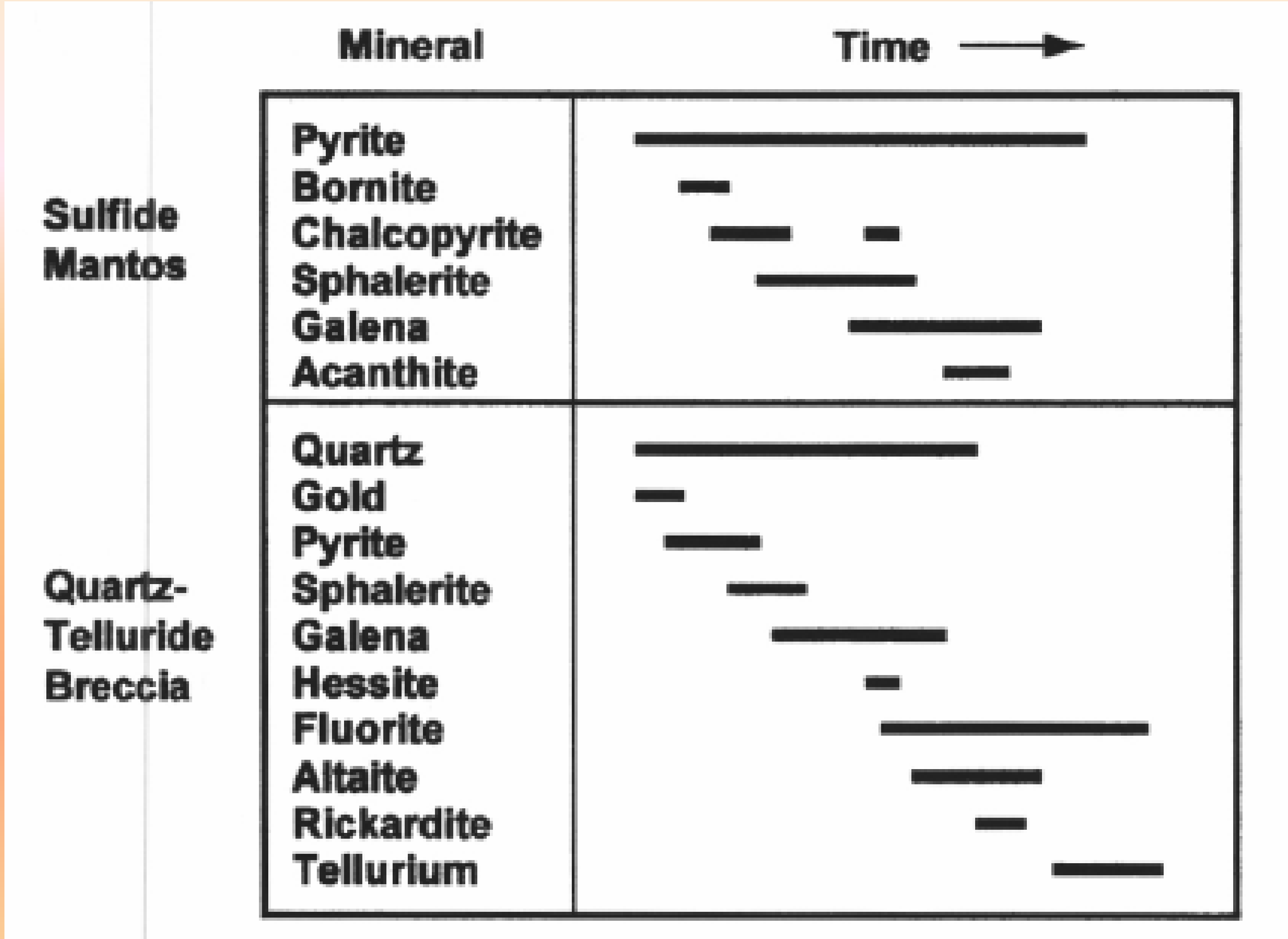


Figure 8—District zoning in the Organ Mountains, Doña Ana County, New Mexico (modified from Dunham, 1935; Seager, 1981).

Lueth and McLemore (1998) and McLemore et al. (1996)

Minerals

- ALTAITE (PbTe)
- RICKARDITE (Cu_3Te_2)
- TETRADYMITE (Bi_2Te_2S)



Paragenesis (Lueth, 1998)

Origin of Te mineralization

- Part of the porphyry copper system

OR

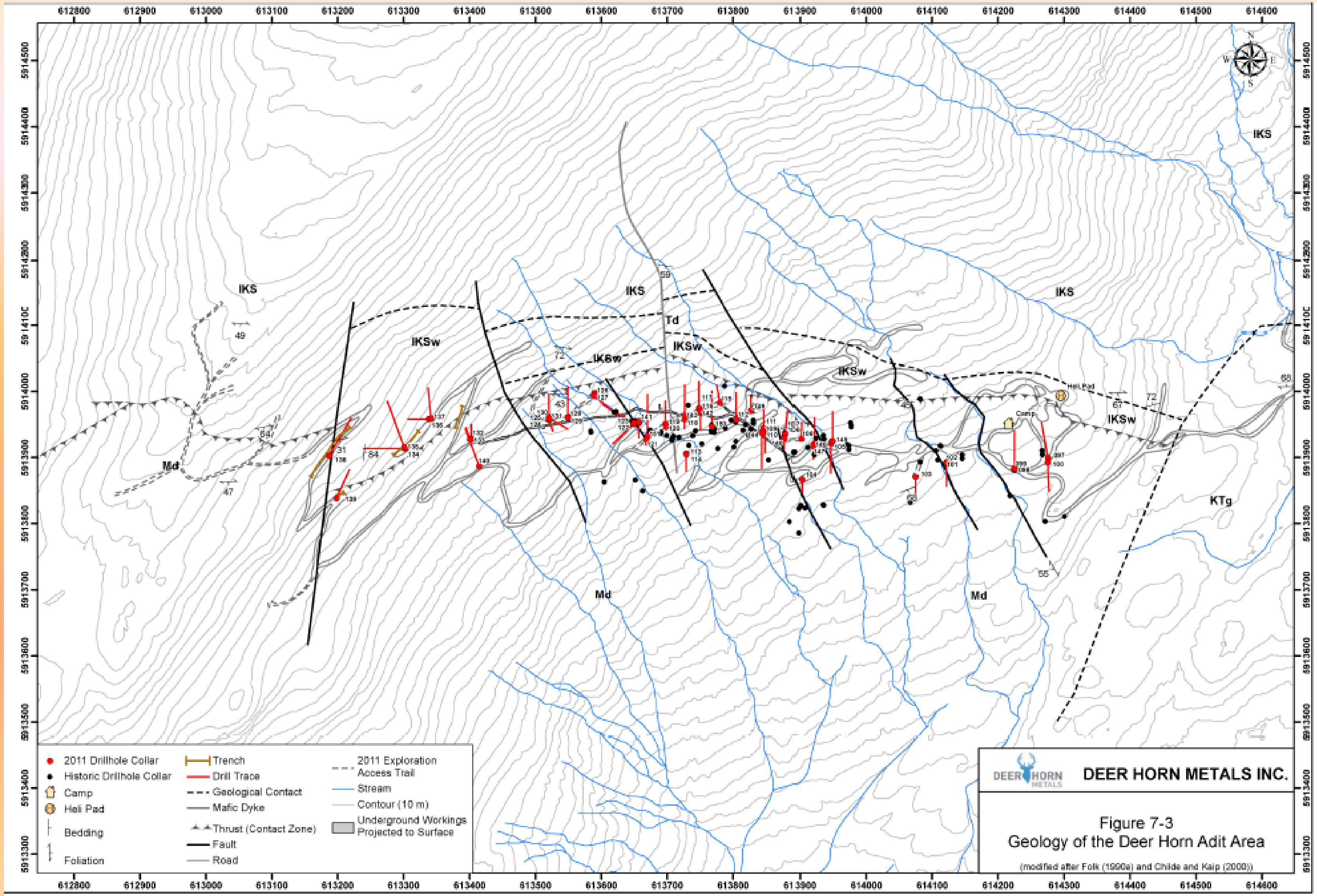
- Superimposed on the porphyry system as a retrograde phase

OR

- Separate event

Deer Horn, British Columbia

- Au-Ag-Te deposit (some Mo, W)
- 1.5 km long
- May be the only NI 43-101 resources for Te



http://www.deerhornmetals.com/i/pdf/reports/2013-03-12_PEA-NI43-101.pdf

Figure 7-4 Common geometric arrangements of fault-filled and extensional veins in shear zones

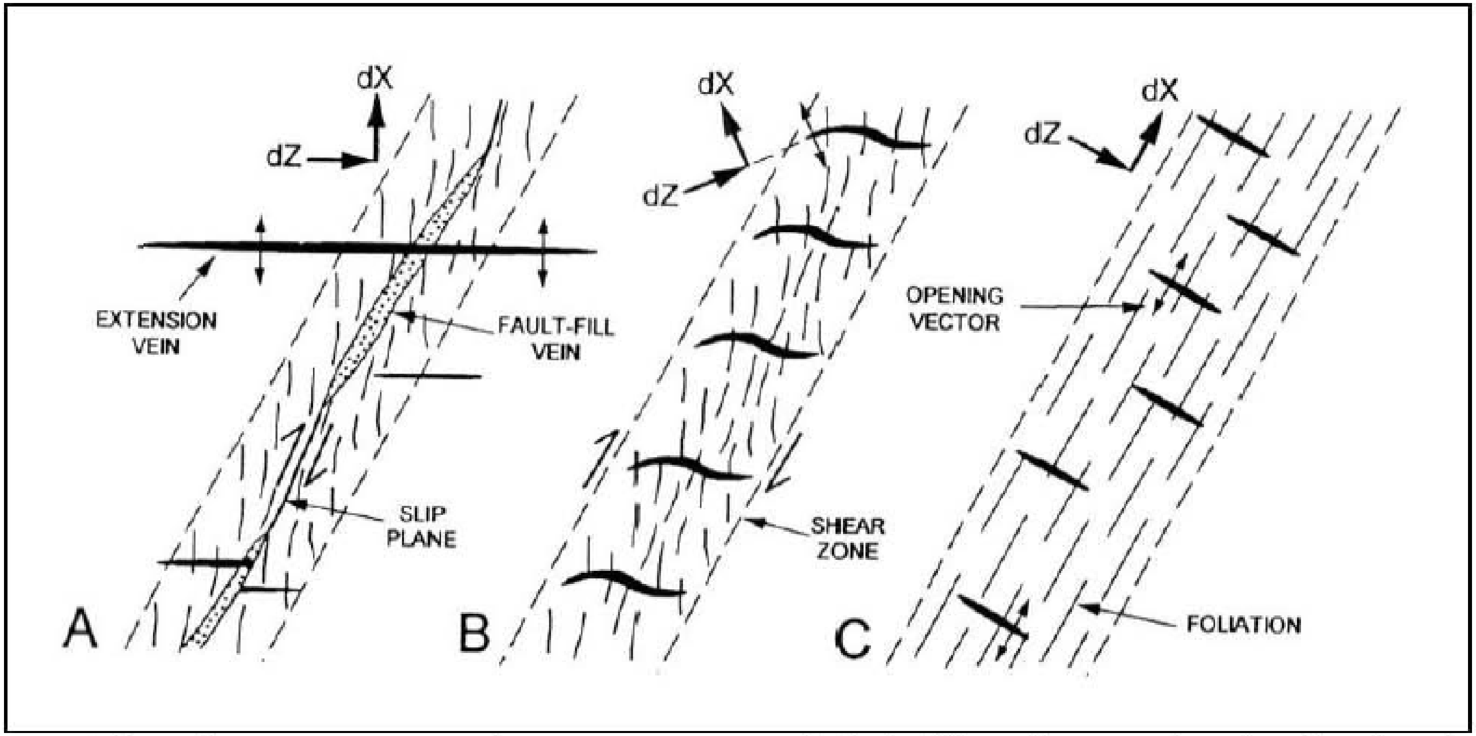
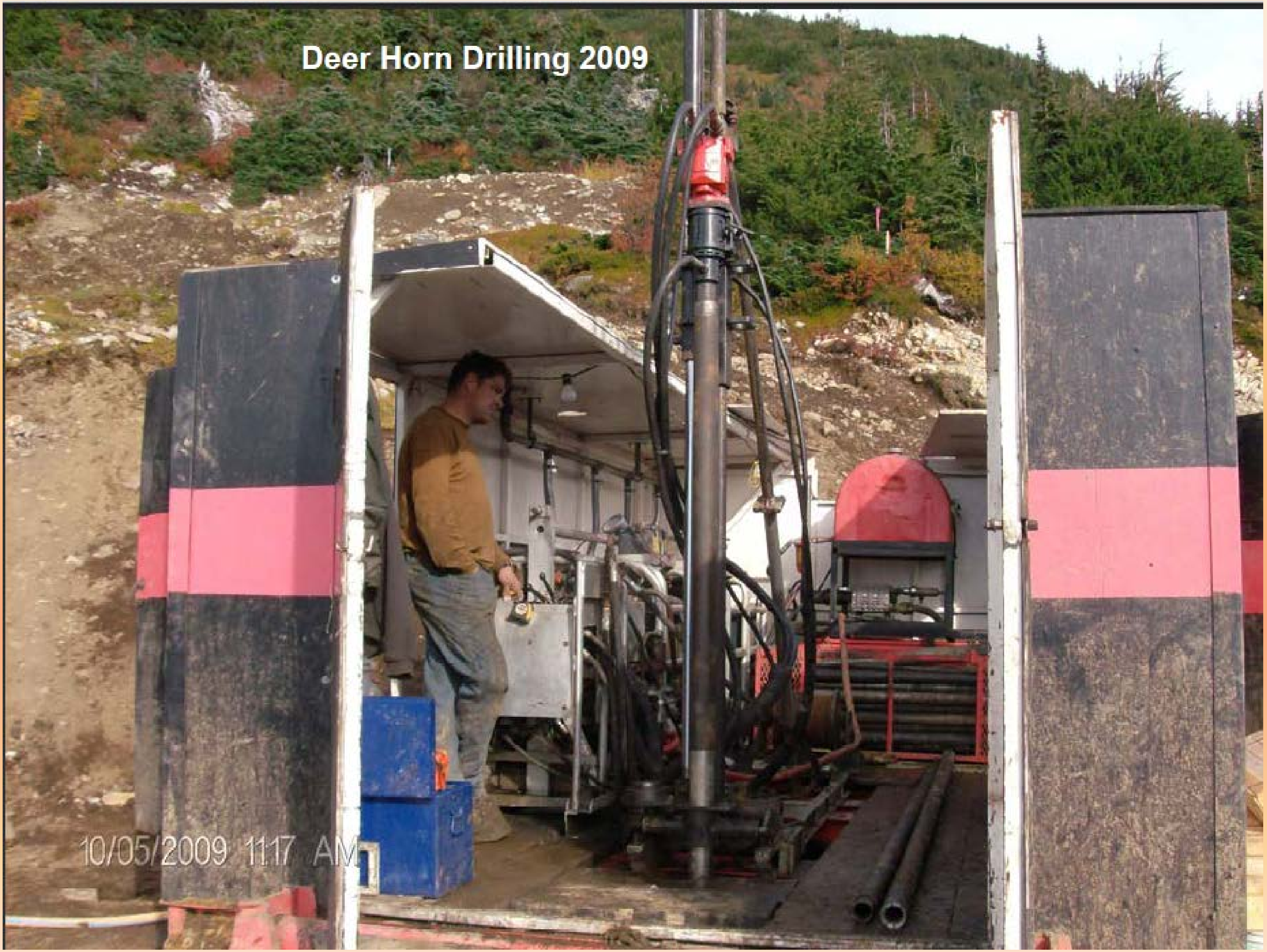
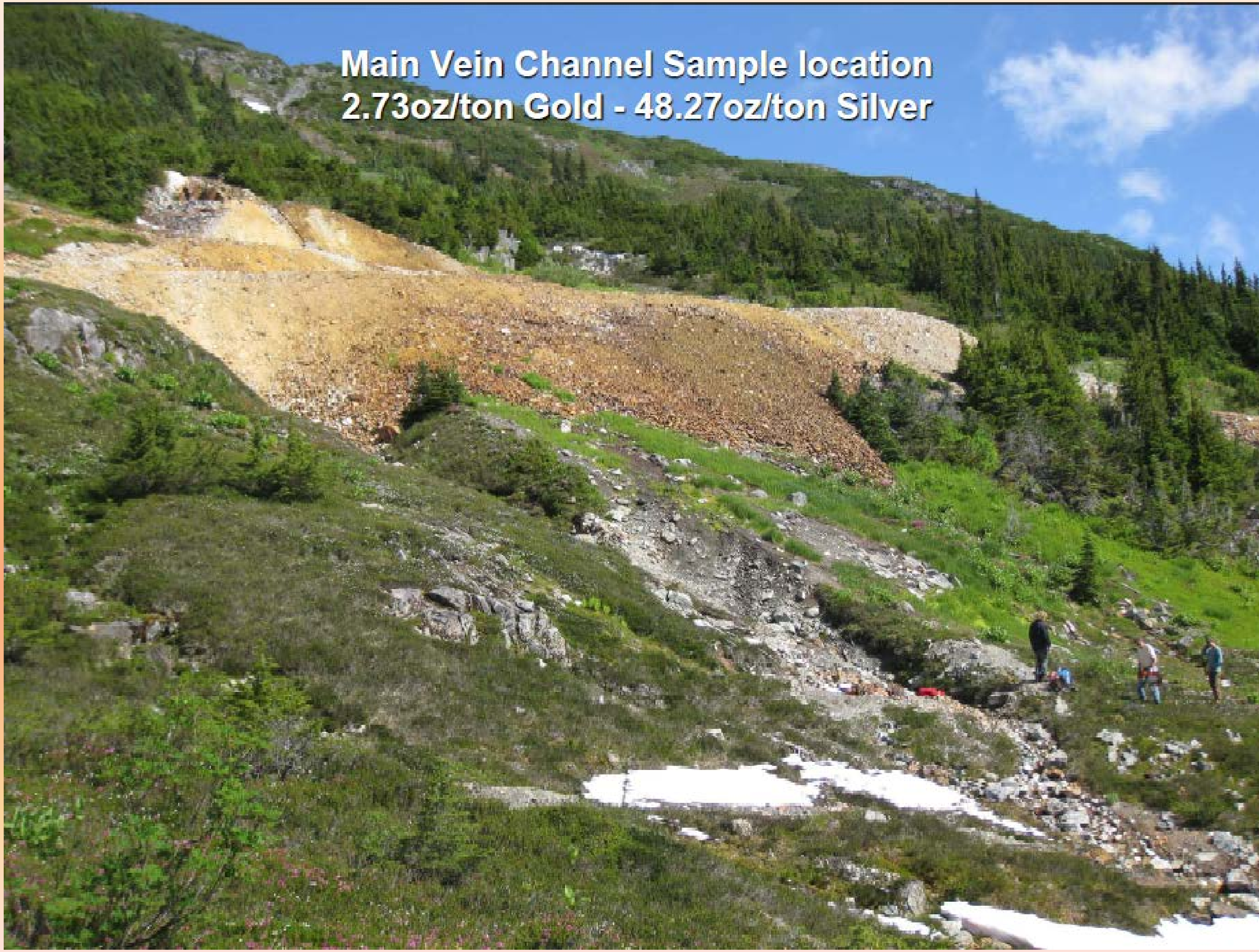


Figure 7-4 shows common geometric arrangements of fault-filled and extensional veins in shear zones and their relationship to incremental axes of shortening (dZ) and elongation (dX). A) Fault-filled veins in the central part of a reverse shear zone showing conflicting crosscutting relationships with planar extensional veins extending outside the shear zone; B) Arrays of en echelon sigmoidal extensional veins within shear zones; C) Arrays of stacked planar extensional veins within shear zones (Robert and Poulsen, 2001).


Deer Horn Drilling 2009
10/05/2009 11:17 AM

Quartz – Sulphide Vein Mineralization, Contact Zone (DH09-072 @ 36.58 m)


Main Vein Channel Sample location
2.73oz/ton Gold - 48.27oz/ton Silver

Deer Horn, British Columbia

Indicated Resource
(1.00 g/t Au cut-off)

Tonnes	Au (g/t)	Ag (g/t)	Te (ppm)	Contained Ounces Au	Contained Ounces Ag	Contained Kg Te
414,000	5.12	157.50	160	68,000	2,120,000	66,000

Inferred Resource
(1.00 g/t Au cut-off)

Tonnes	Au (g/t)	Ag (g/t)	Te (ppm)	Contained Ounces Au	Contained Ounces Ag	Contained Kg Te
197,000	5.04	146.50	137	32,000	930,000	27,000

http://www.deerhornmetals.com/i/pdf/nr/2012-04-17_NR.pdf

Production highlights for the 14 year mine life are as follows:

Total Tonnes to Mill	949,000
Annual Tonnes to Mill	74,000
Average Grades:	
Gold (grams per tonne)	2.45
Silver (grams per tonne)	77
Tellurium (ppm)	74
Total Production:	
Gold (ounces)	67,000
Silver (ounces)	2,112,000
Tellurium (kg)	63,000

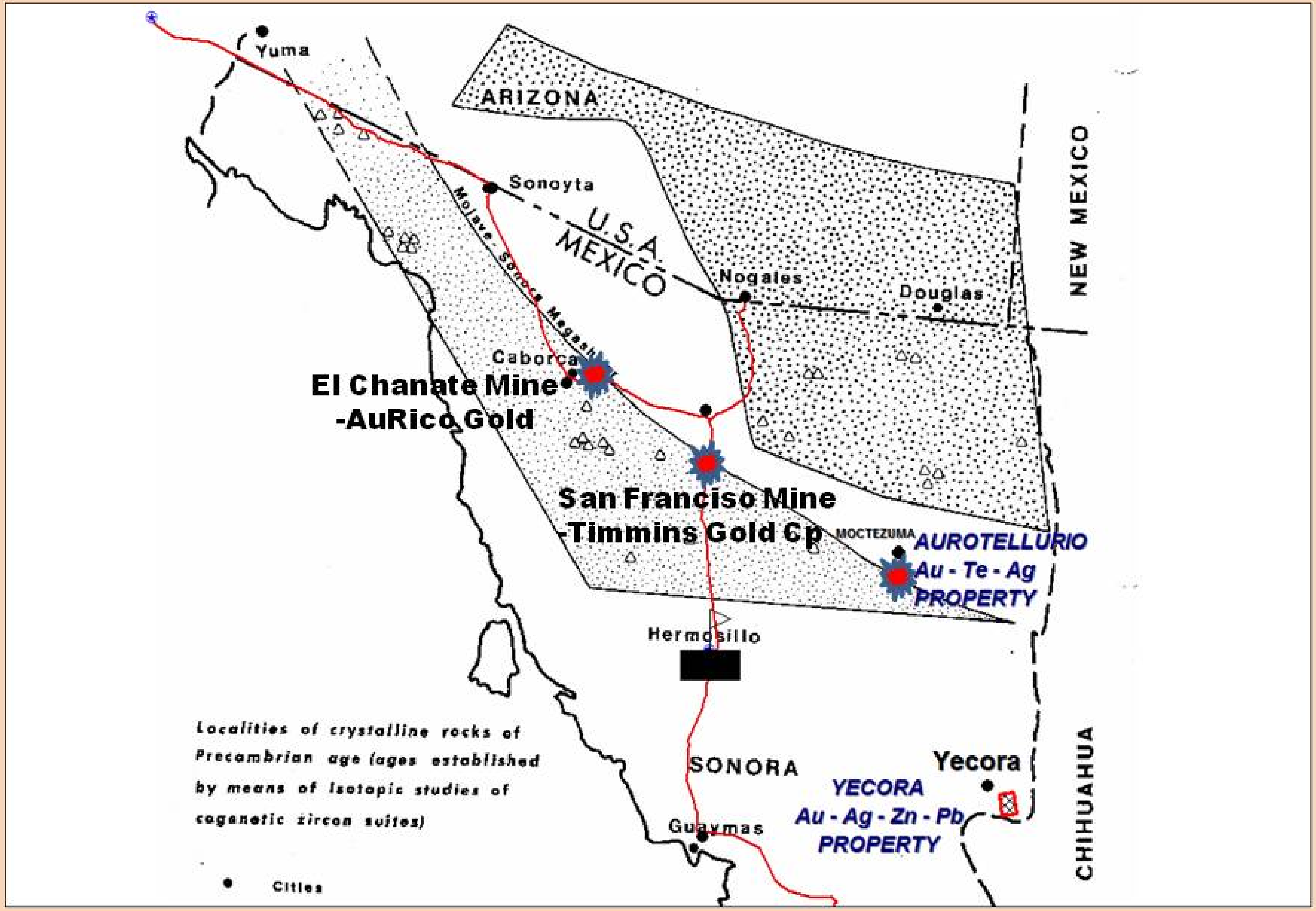
http://www.deerhornmetals.com/s/news.asp?ReportID=576227

Moctezuma district, Mexico

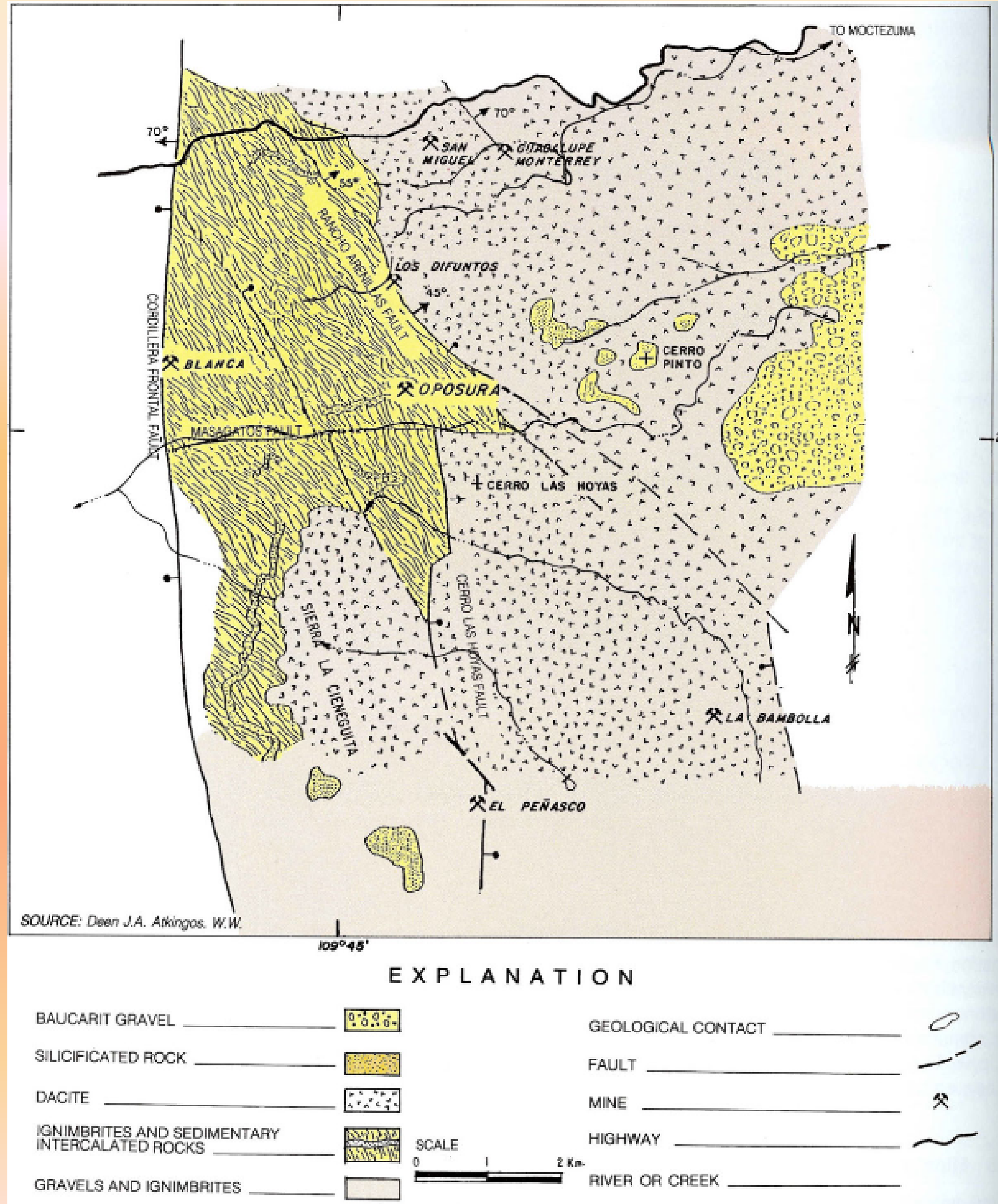
Moctezuma district, Mexico

- replacement-style zinc-lead base metal deposits in mantos (Oposura)
- Structure-controlled veins
- Quartz and quartz-carbonate (San Miguel and La Bambolla, Blanca Norte)

AUROTELLURIO Regional Map



http://www.mexivada.com/i/maps/mx/AuroTellurio-Regional-Map.jpg



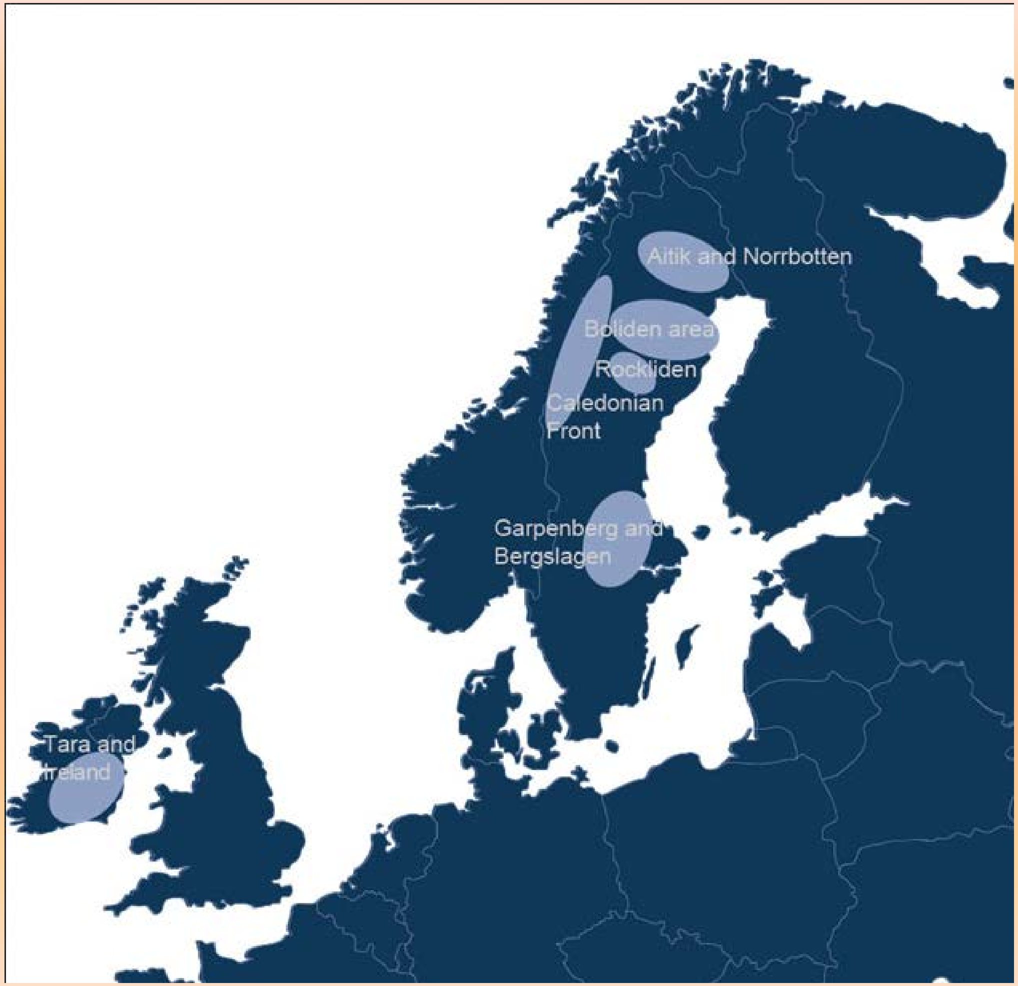
http://www.mexivada.com/i/maps/mx/Moctezuma_Geology.jpg

SAMPLE	Au-AA24	ME-MS61 Ag	ME-MS61 Te
51401	<0.005	357	0.07
51402	<0.005	220	0.05
51403	<0.005	17.2	<0.05
51404	<0.005	6.88	12.95
51405	<0.005	0.33	0.47
51406	0.008	16.85	0.28
51407	0.011	13.85	0.25
51408	0.005	32.1	0.57
51409	<0.005	0.63	0.08
51410	0.007	0.17	3.96
51411	0.183	20.1	5.4
51412	0.059	0.72	16.55
51413	0.015	0.49	2.07

Table 3. Surface Sampling in the Moctezuma Mining District.

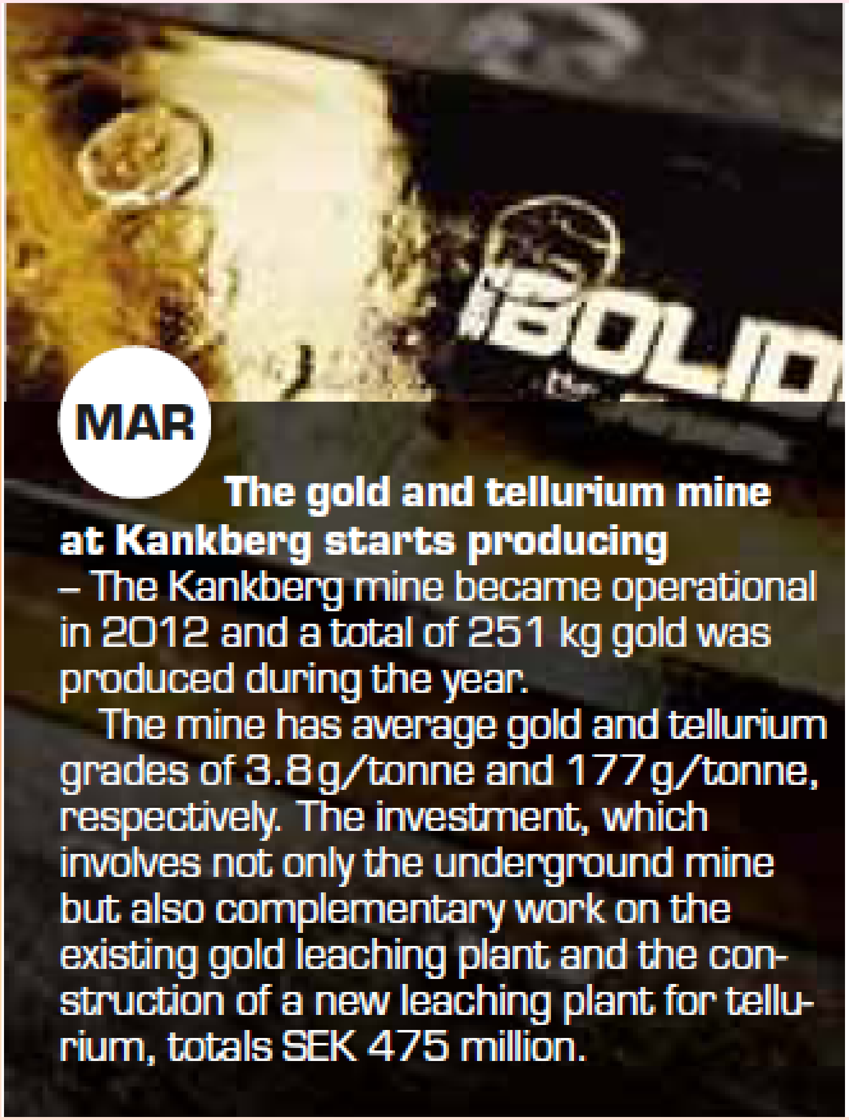
http://www.mexivada.com/i/pdf/AuroTellurio_techreport_4-09.pdf

Kankberg, Boliden in Sweden



Kankberg

- Skellefte district
- VMS deposit
- Previously operated for Cu-Zn in the 1990s
- Underground
- Concentrator and gold-recovery plant



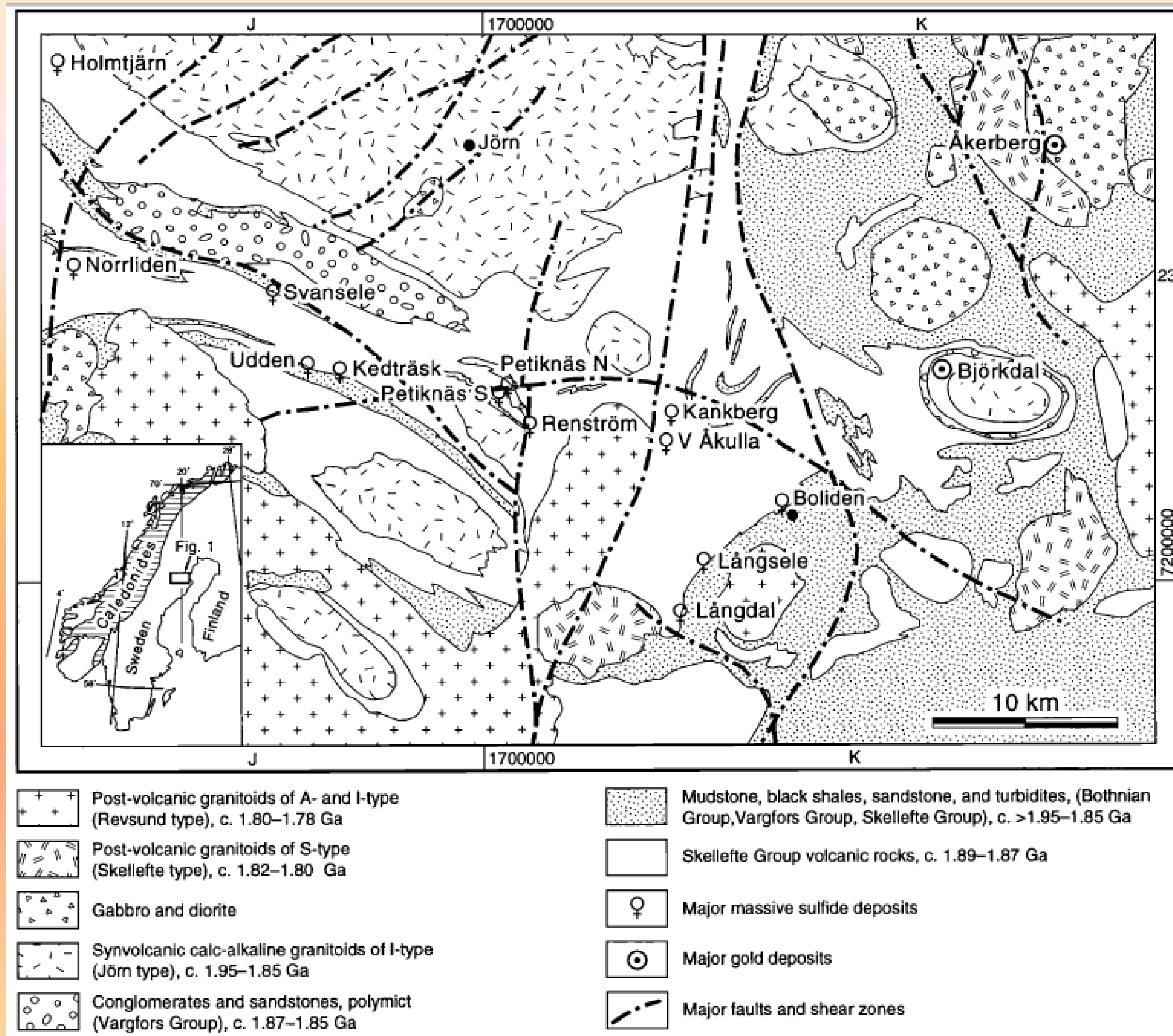


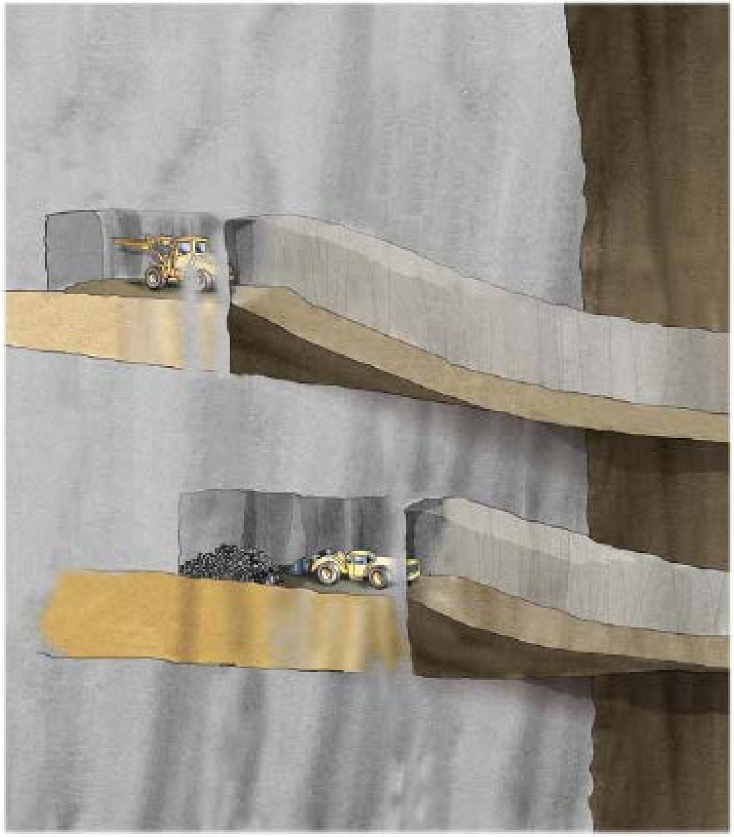
FIG. 1. Simplified geology of the Skellefte district with the location of the Boliden deposit. Modified from Allen et al. (1996). Coordinates in national grid.

Weihed et al., Econ Geol, v. 91, 1996

The project

- Project includes
  - Mine facilities
  - Underground development
  - Leaching plant rebuilding
- Production until 2020
  - Gold 1,150 kg average annual volume
  - Tellurium 41 tonnes average annual volume
- Start of production mid 2012

- Ore reserve 2,880 ktonnes
- Average grades
  - Gold 4.1 g/tonne
  - Tellurium 186 g/tonne



NEW BOLIDEN

http://www.boliden.com/Documents/Press/Presentations/Kankberg.pdf

Kankberg – a new gold mine

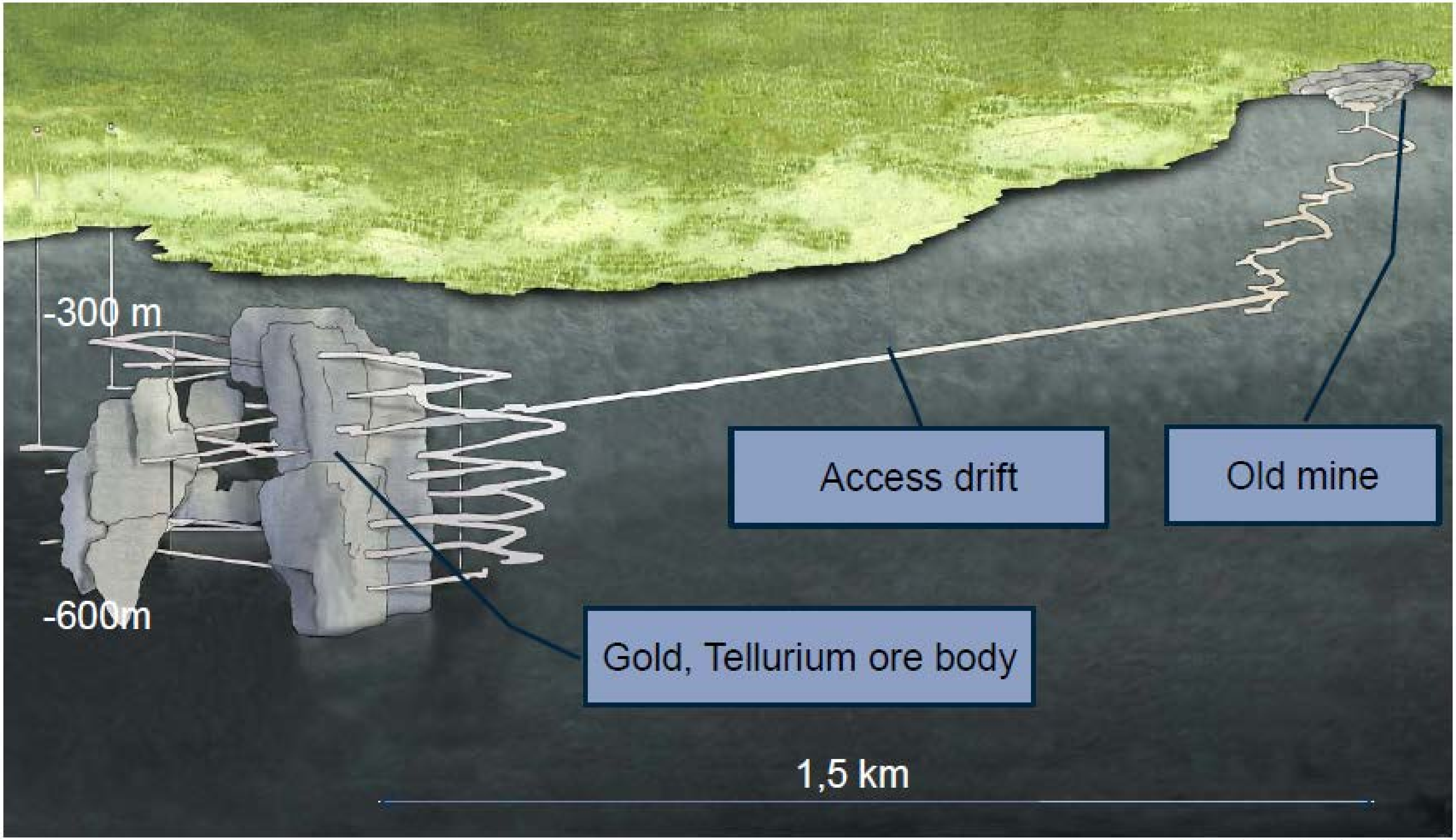
- Mineral reserve: 3,100 ktonnes
- Average grades
  - Gold 4.1 g/tonne
  - Tellurium 186 g/tonne
- Production between 2012-2020
  - Ore 320,000 tonnes
  - Gold 1,150 kg[1)]
  - Tellurium 41 tonnes[1)]
- The SEK 475 million investment includes:
  - Mine infrastructure
  - A new leaching plant
- Production starts in mid-2012

1) Metal content

NEW BOLIDEN

http://www.boliden.com/Documents/Press/Presentations/Group_Presentation_Boliden.pdf

The Kankberg mine – side view



NEW BOLIDEN

Boliden concentrator
– leaching plant to be rebuilt

NEW BOLIDEN

Boliden Mineral, Mineral Reserves as of December 31, 2012

		2012 Kton	2011 Kton	Au g/t	Ag g/t	Cu %	Zn %	Pb %	Mo g/t	Te g/t
Boliden Area										
Polymetallic Mineralizations										
Kristineberg	Proven	1,000	*1,020*	1.3	24	1.4	1.8	0.1		
	Probable	3,600	*3,800*	0.5	42	0.4	7.1	0.4		
Renström	Proven	140	*140*	3.0	137	0.6	7.5	1.5		
	Probable	2,840	*2,180*	2.1	121	0.9	5.6	1.1		
Maurliden	Proven	1,300	*1,300*	1.3	51	0.2	3.6	0.4		
	Probable									
Maurliden Östra	Proven									
	Probable	190	*520*	0.5	14	1.0	0.2			
Total	**Proven**	**2,430**	***2,460***	**1.4**	**45**	**0.7**	**3.1**	**0.3**		
Polymetallic Min.	**Probable**	**6,680**	***6,500***	**1.2**	**74**	**0.6**	**6.2**	**0.7**		
Gold Mineralizations										
Kankberg	Proven	1,050	*500*	2.7	10					161
	Probable	2,530	*2,600*	4.3	16					184
Aitik	**Proven**	**476,000**	***486,000***	**0.14**	**1.5**	**0.24**			**26**	
	Probable	**226,000**	***224,000***	**0.15**	**1.7**	**0.26**			**30**	
Garpenberg	**Proven**	**15,400**	***17,400***	**0.3**	**117**	**0.06**	**5.5**	**2.2**		
	Probable	**10,200**	***6,200***	**0.3**	**151**	**0.05**	**4.6**	**1.9**		
Tara	**Proven**	**2,300**	***3,300***				**7.5**	**1.8**		
	Probable	**11,700**	***12,400***				**7.1**	**1.7**		

Roundings may occur

Pb-Zn veins

- Romania, Bulgaria and Russia
- veins, lens-shaped and metasomatic bodies within granites, volcanic-sedimentary, acid granites and alkaline derivatives
- Altaite
- Zyryanovsk, Russia with galena containing 150ppm Te in the oxidation zone, as altaite
- Baia de Aries, Romania, where the Te field occurs in the western part of the metallogenic area, as vein bodies

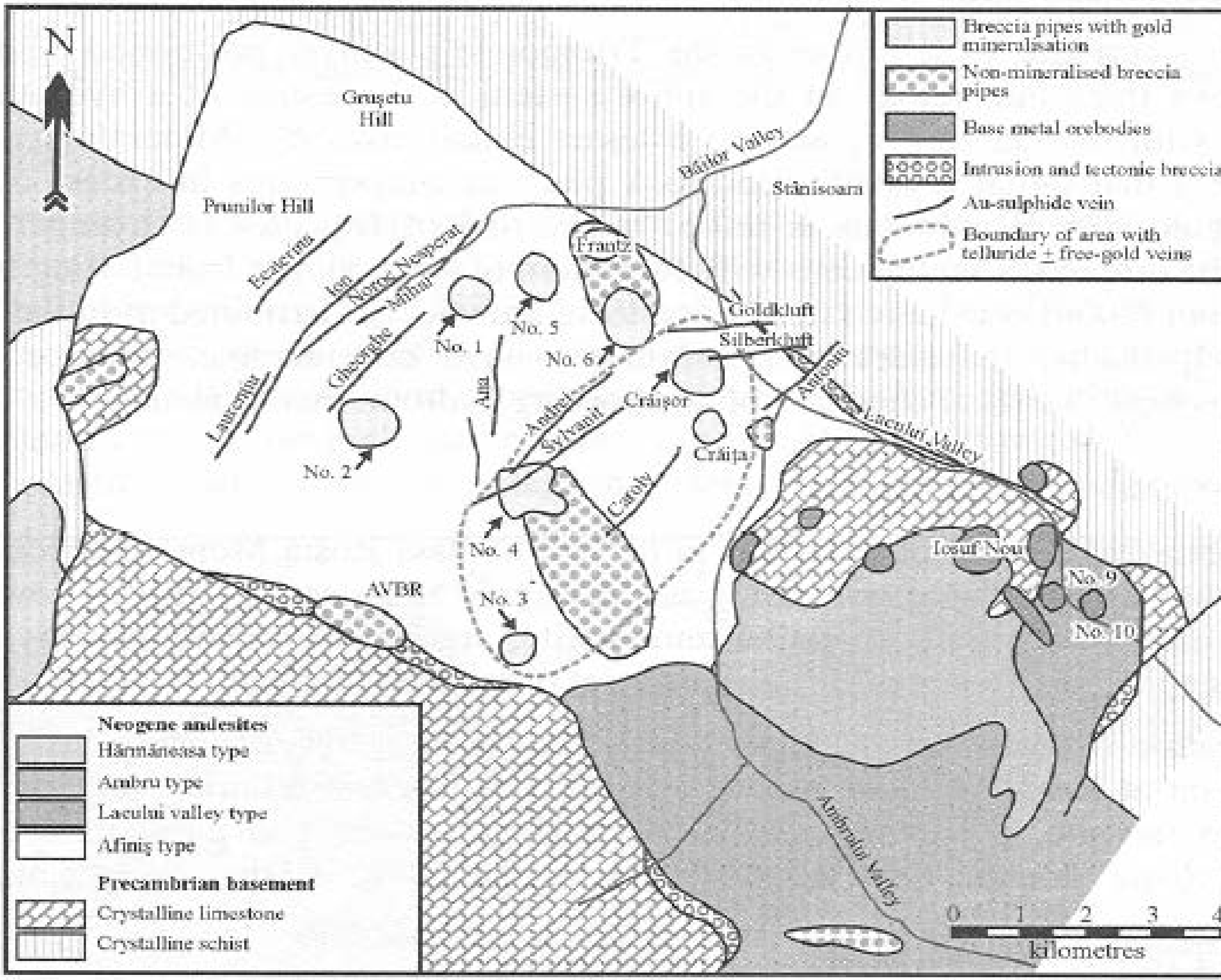
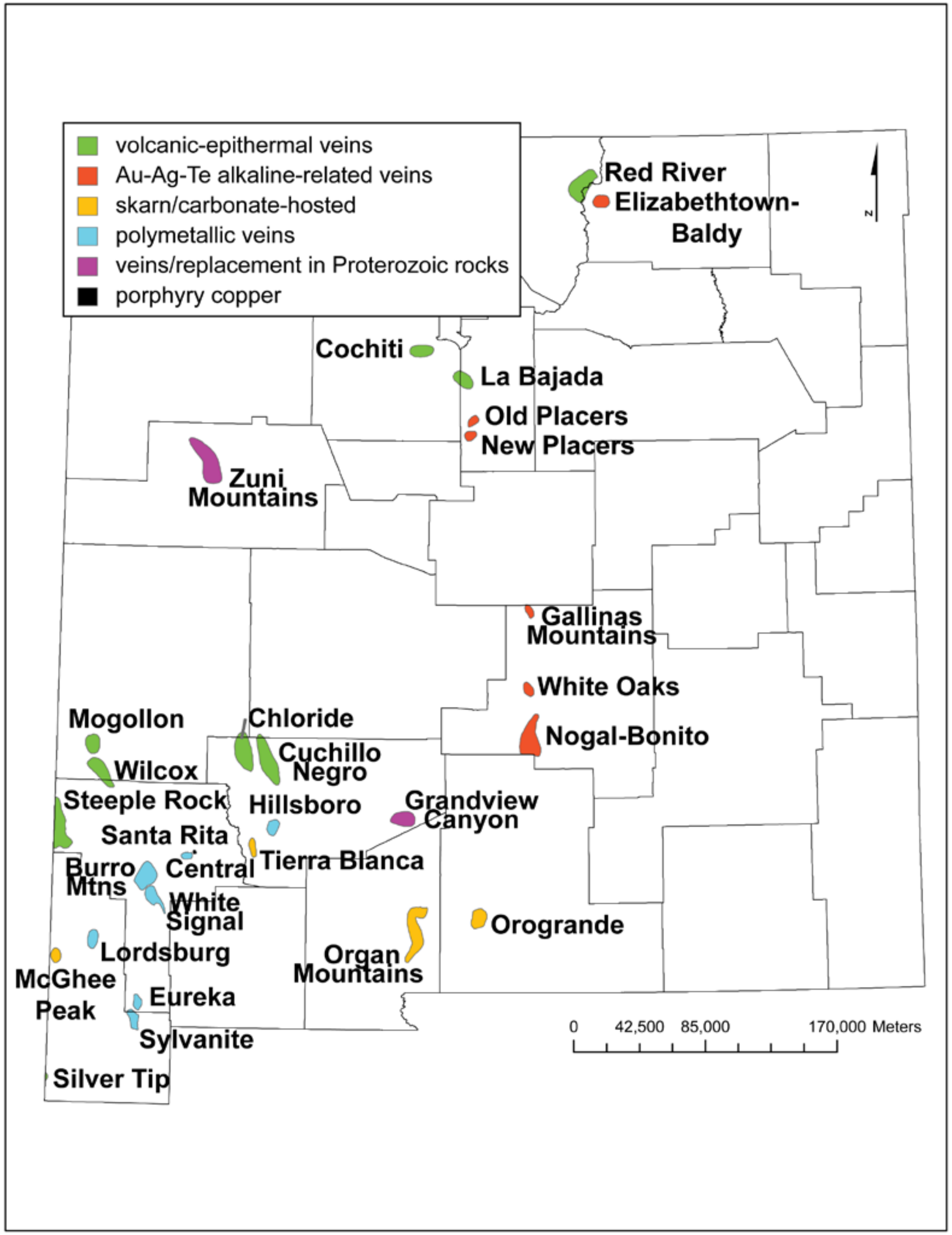


Fig. 3 Simplified geological map of the Baia de Aries deposit (Ciofica et al., 1999)

Lone Pine, Wilcox district, Catron County—volcanic epithermal vein

Mining districts in New Mexico with tellurium minerals or chemical assays >20 ppm Te



Production

- Discovered about 1889

- 5 tons of Te 1961-1962
- 1.23 oz Au
- 19 oz Ag
- 10,603 tons of fluorite

Geology

- Hosted by volcanic rocks
- Fracture fillings and veinlets
- Along north- and northwest-trending fractures and faults that were intruded by rhyolite dikes
- Clay alteration, locally silicified, hematization
- Pyrite to pyrite-Te to fluorite-rich zones
- 400 to 500 feet long
- up to 1,800 feet long
- As much as 5000 ppm Te, 6 oz/ton Au

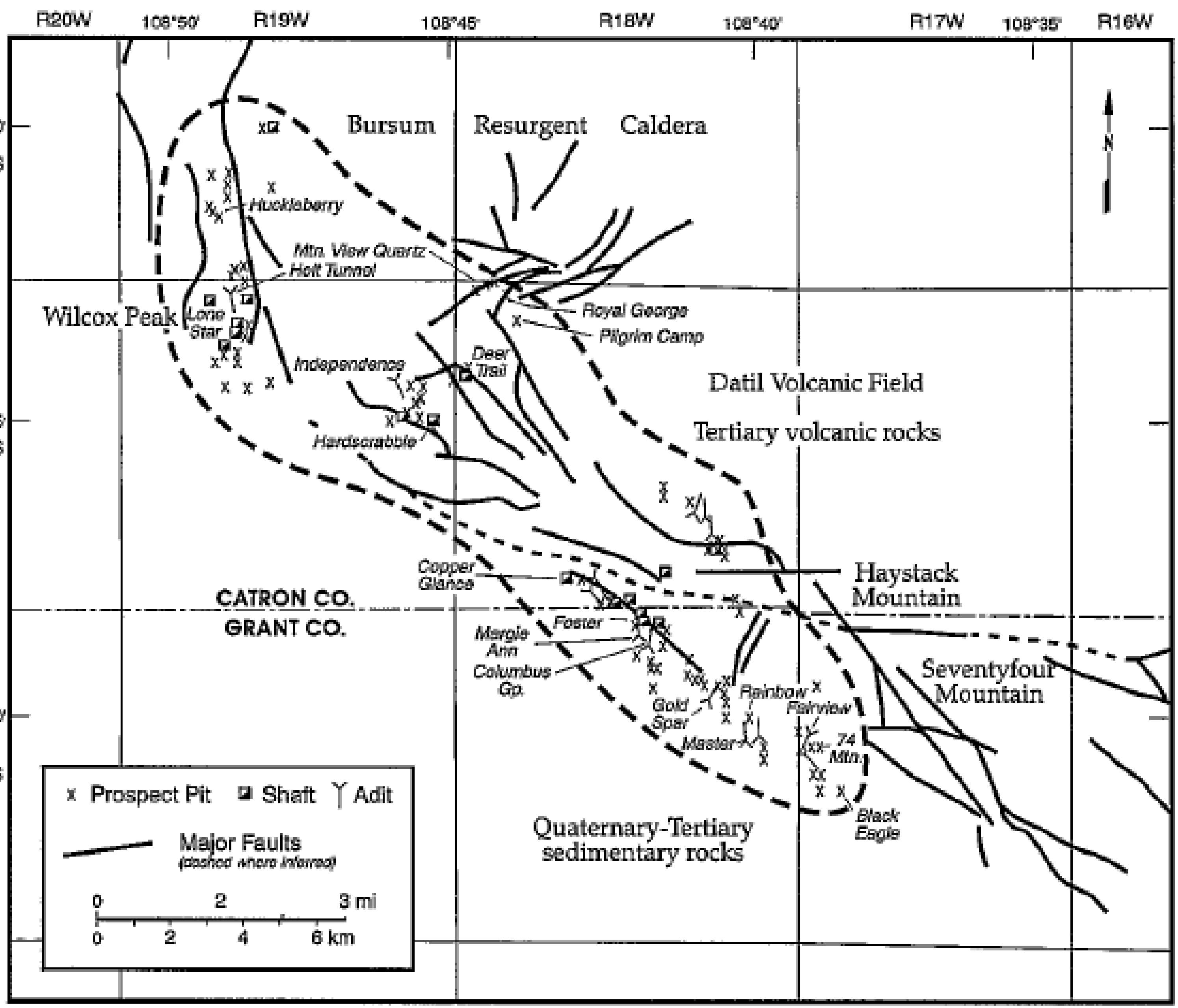
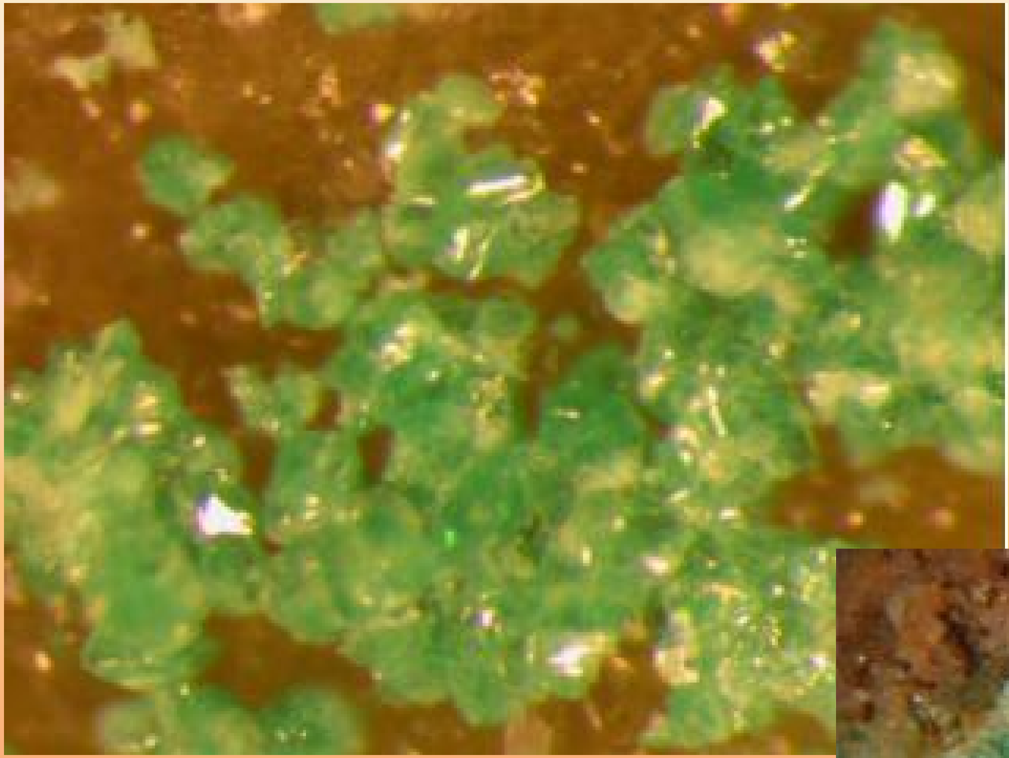


Figure 61—Mines and prospects in the Wilcox mining district, Grant and Catron Counties, New Mexico.

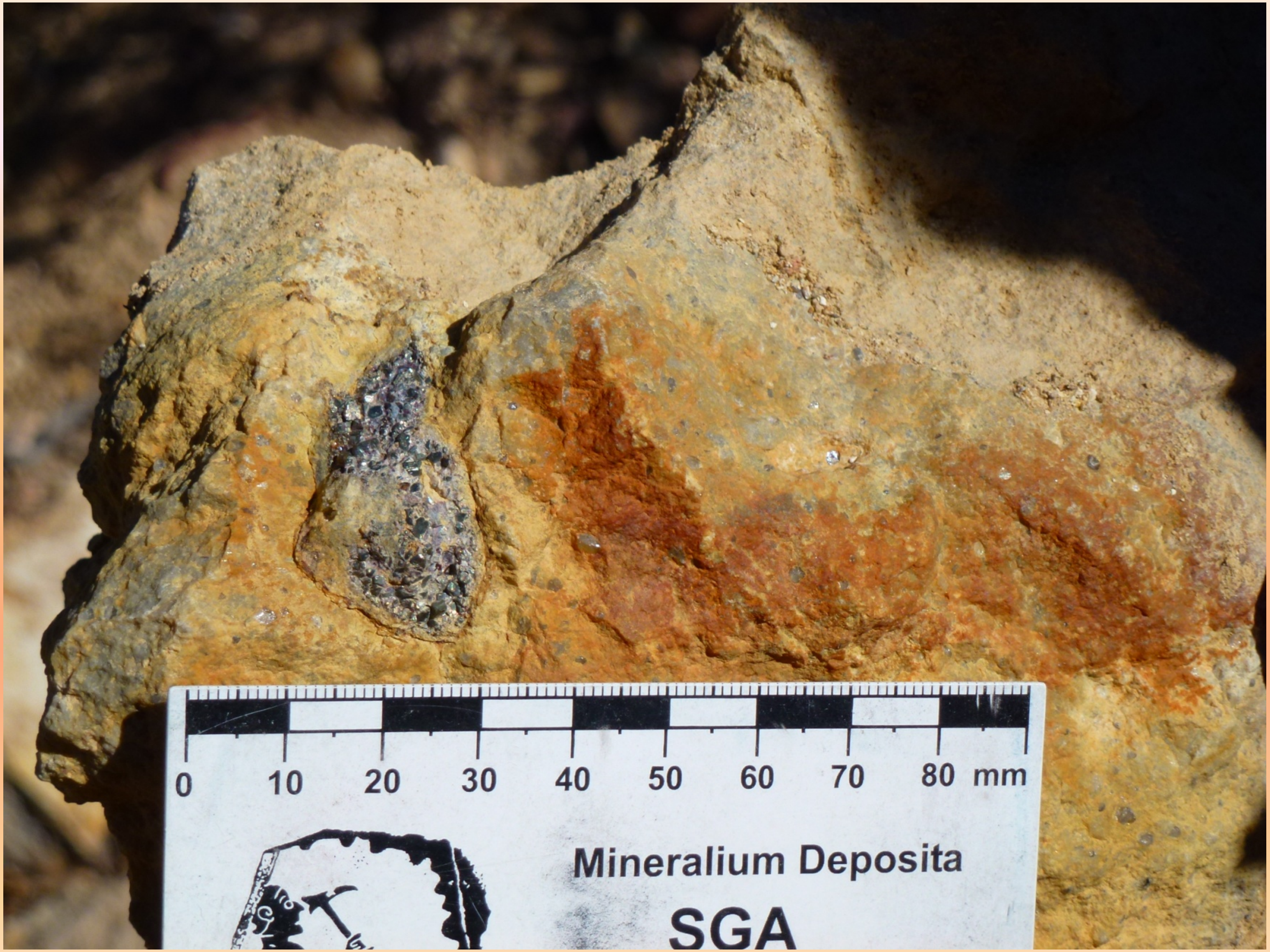
Minerals (Lueth et al., 1995)

- Quartz
- Pyrite
- Acanthite
- Bismuthinite
- Tellurite
- Paratellurite
- Teeurobismuthite
- Native tellurium
- Tetradymite?
- Krennerite(?)
- emmonsite ($Fe_2Te_3O_9 \bullet 2H_2O$)
- mackayite ($FeTe_2O_5(OH)$)
- sonoraite ($FeTeO_3(OH) \bullet H_2O$)
- blakeite ($Fe_2(TeO_3)_3$)
- poughite ($Fe_2(TeO_3)_2(SO_4) \bullet 3H_2O$)
- rajite ($CuTe_2O_5$)



rajite ($CuTe_2O_5$)

http://www.mindat.org/loc-3966.html

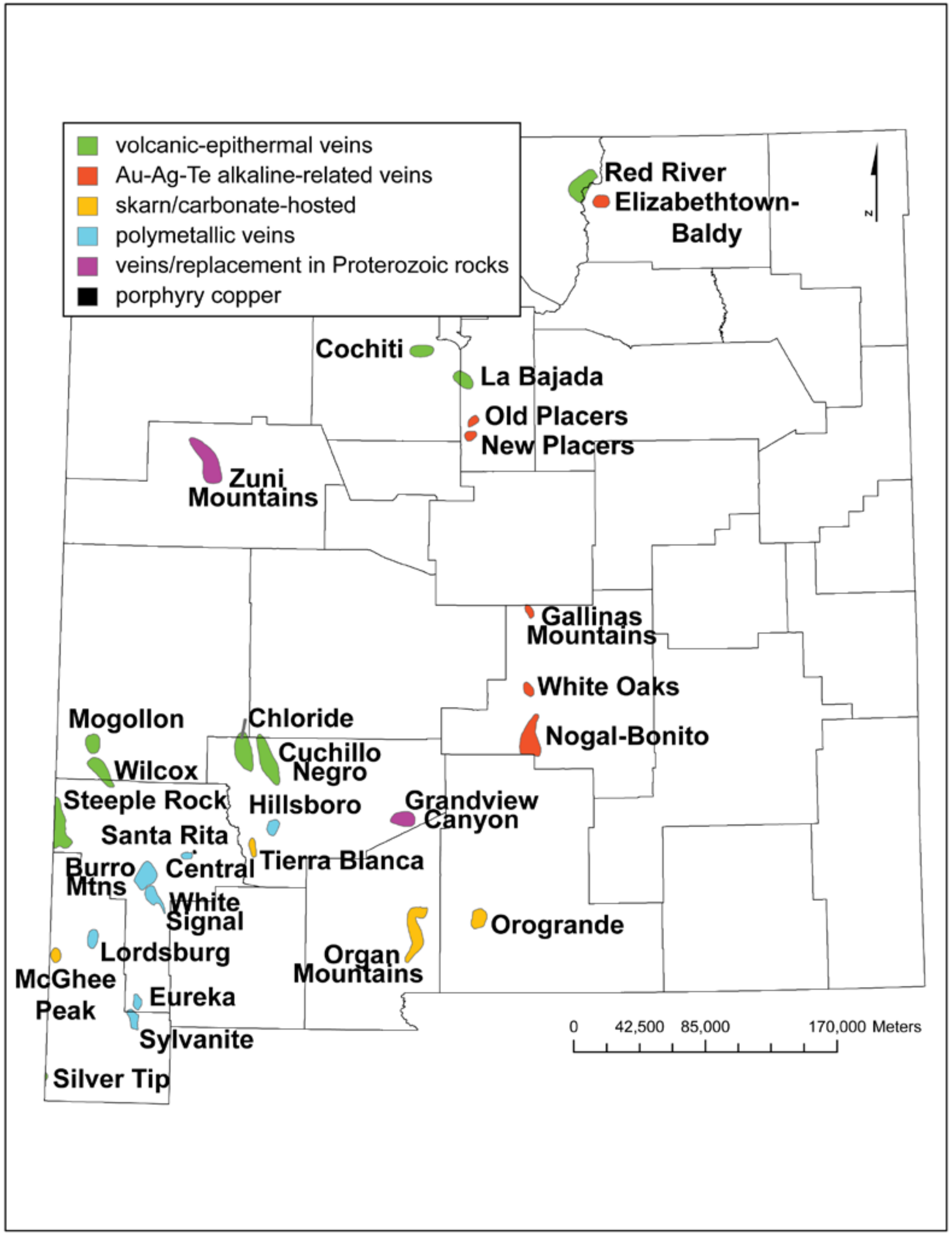


tetradymite (Bi_2Te_2S)

Sylvanite district, New Mexico

Sylvanite, $AgAuTe_4$

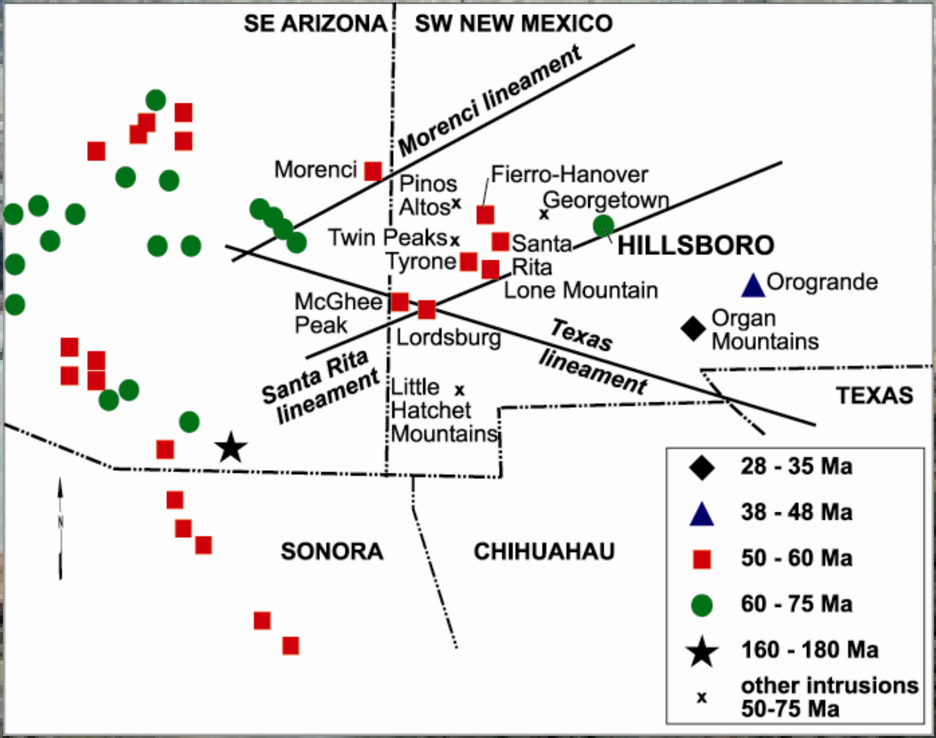
https://www.mineralauctions.com/auctions/weekly-collection-liquidation-auctions-end-march-31-478/sylvanite-old-rare-nm-locale-velte-coll-22476.html



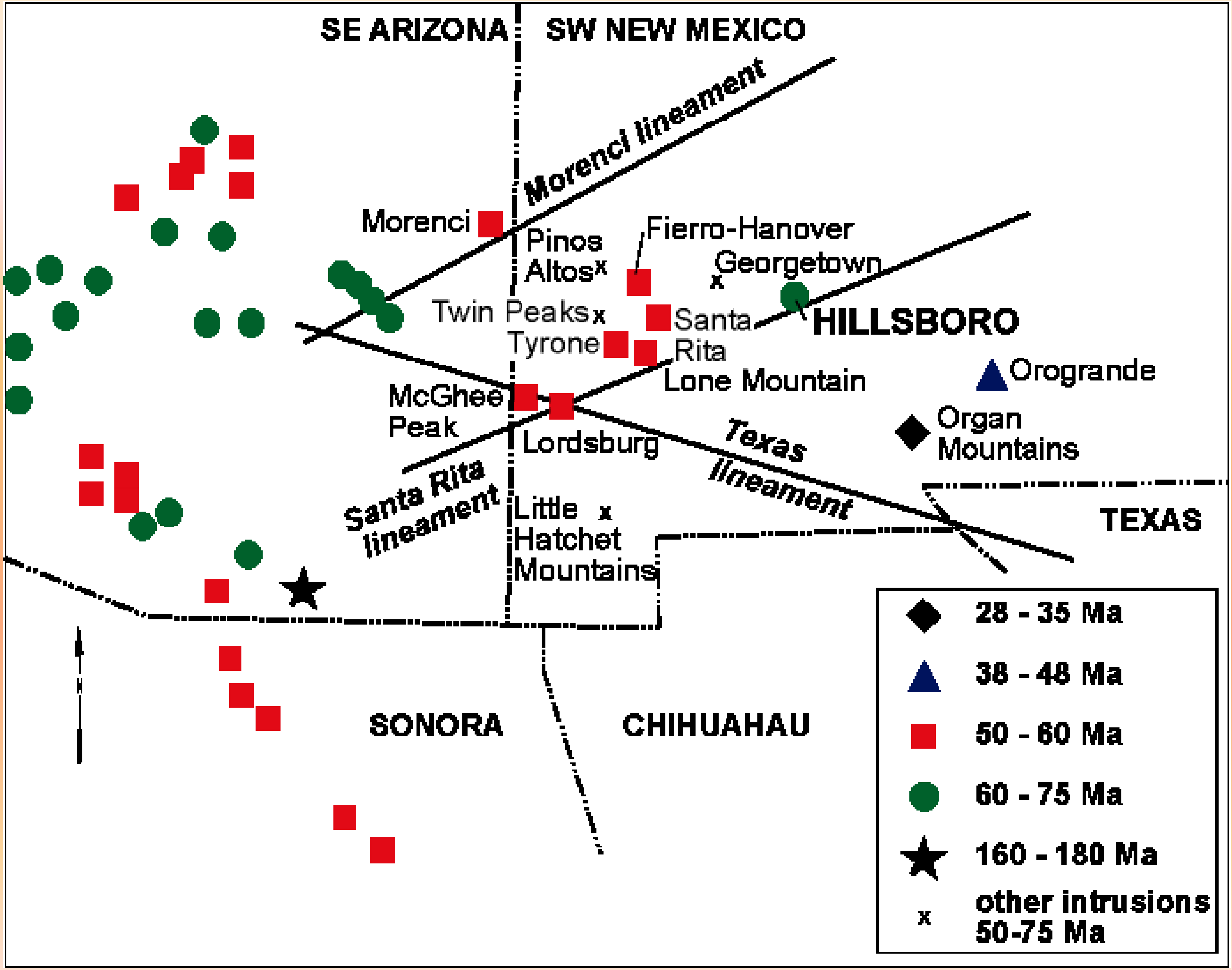
Mining districts in New Mexico with tellurium minerals or chemical assays >20 ppm Te

Laramide Porphyry copper deposits

- Current
  - Gold
  - Silver
  - Molybdenum
- Possible
  - Tellurium
  - Gallium
  - Germanium
  - Indium
  - Others

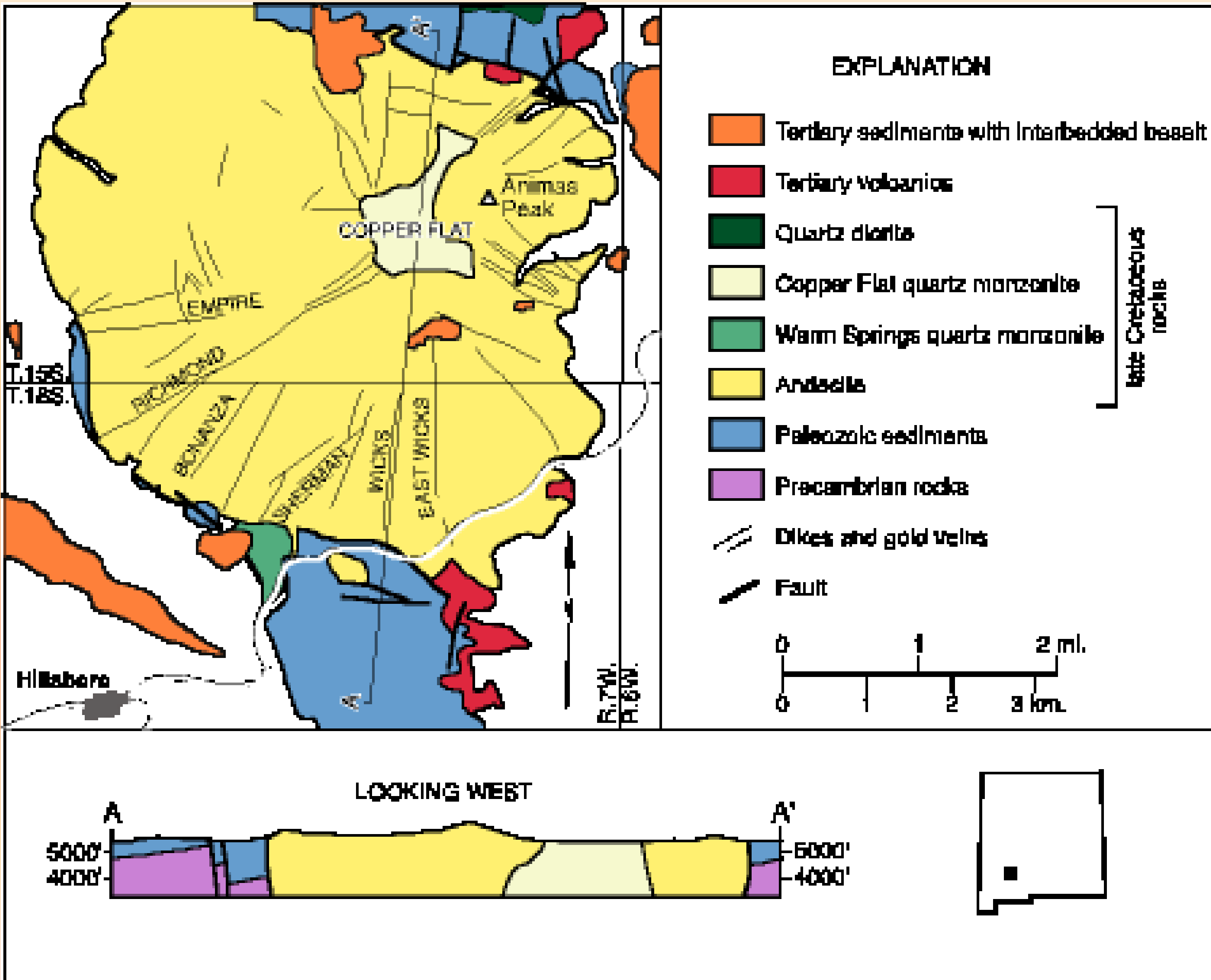


Copper Flat, Hillsboro, Sierra County, NM


SE ARIZONA
SW NEW MEXICO
Morenci lineament
Morenci
Pinos
Altos x
Fierro-Hanover
Georgetown
x
Twin Peaks x
Santa
Rita
HILLSBORO
Tyrone
Lone Mountain
Orogrande
McGhee
Peak
Lordsburg
Organ
Mountains
Texas
lineament
Santa Rita
lineament
Little
Hatchet
Mountains
x
TEXAS
SONORA
CHIHUAHAU
28 - 35 Ma
38 - 48 Ma
50 - 60 Ma
60 - 75 Ma
160 - 180 Ma
x
other intrusions
50-75 Ma

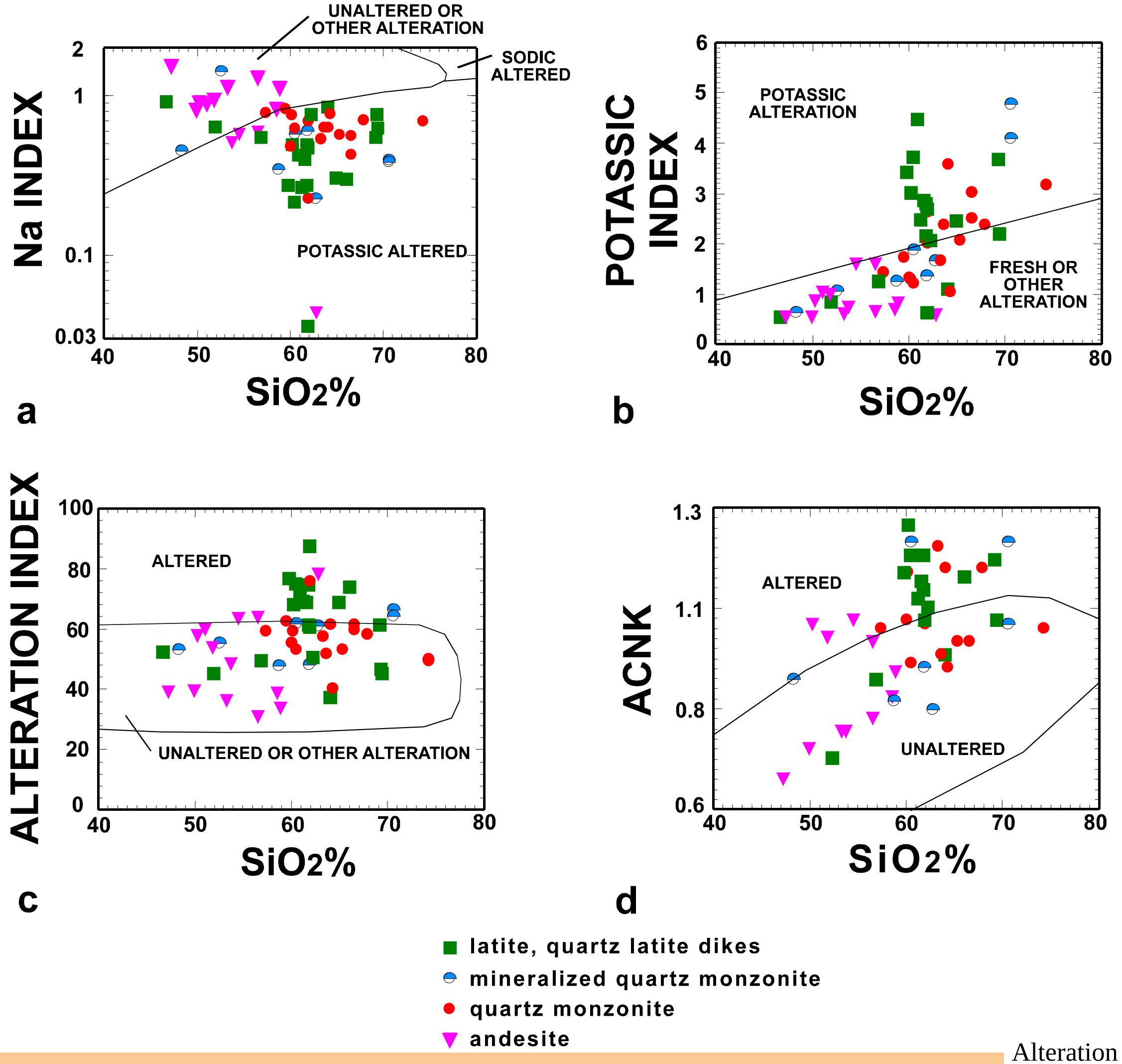
Copper Flat

- proven and probable reserves of 45.5Mt of ore at a reported grade of 0.45% Cu, 0.14g/t Au, 2.3 g/t Ag and 0.0015% Mo
- quartz monzonite stock (CFQM; 74.93±0.66 Ma) with a breccia pipe is located in the center of the district
- Surrounded by Laramide veins and carbonate-hosted Pb-Zn and Ag-Mn deposits

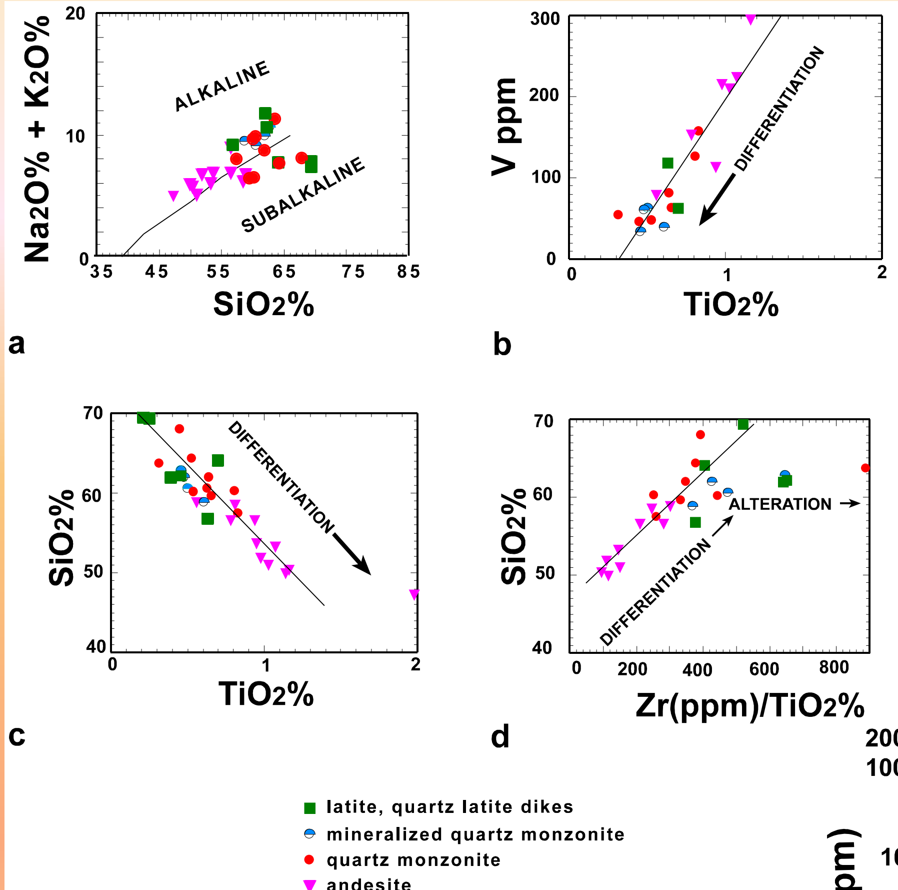


EXPLANATION
Tertiary sediments with interbedded basalt
Tertiary volcanics
Quartz diorite
Copper Flat quartz monzonite
Warm Springs quartz monzonite
Andesite
late Cretaceous rocks
Paleozoic sediments
Precambrian rocks
Dikes and gold veins
Fault
0 1 2 mi.
0 1 2 3 km.
Animas Peak
COPPER FLAT
EMPIRE
RICHMOND
BONANZA
SHERMAN
WICKS
EAST WICKS
T.15S.
T.16S.
R.7W.
R.6W.
Hillsboro
A
A'
LOOKING WEST
5000'
4000'

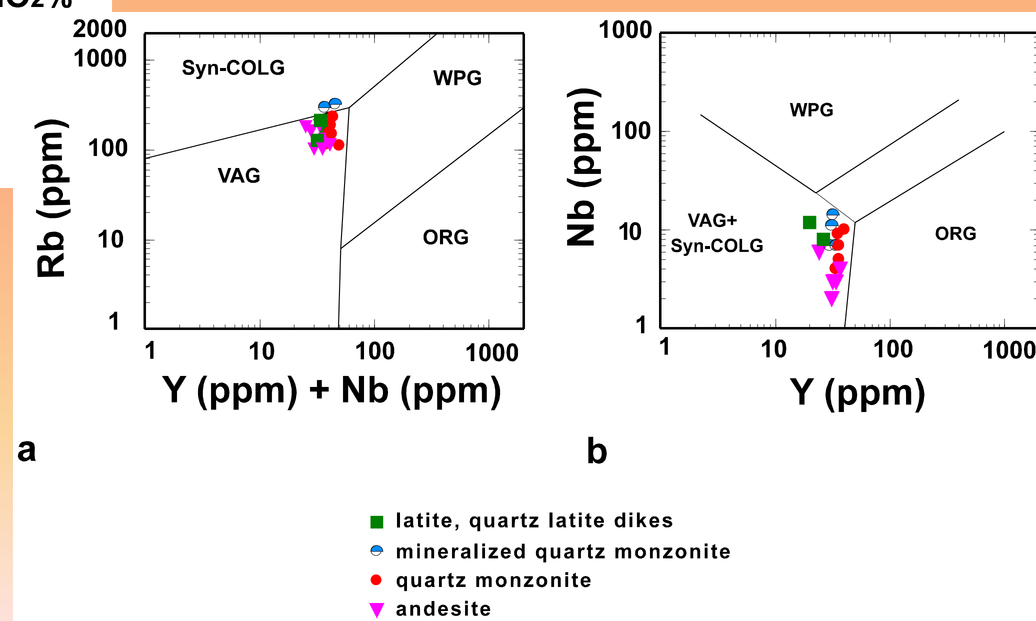
Chemistry



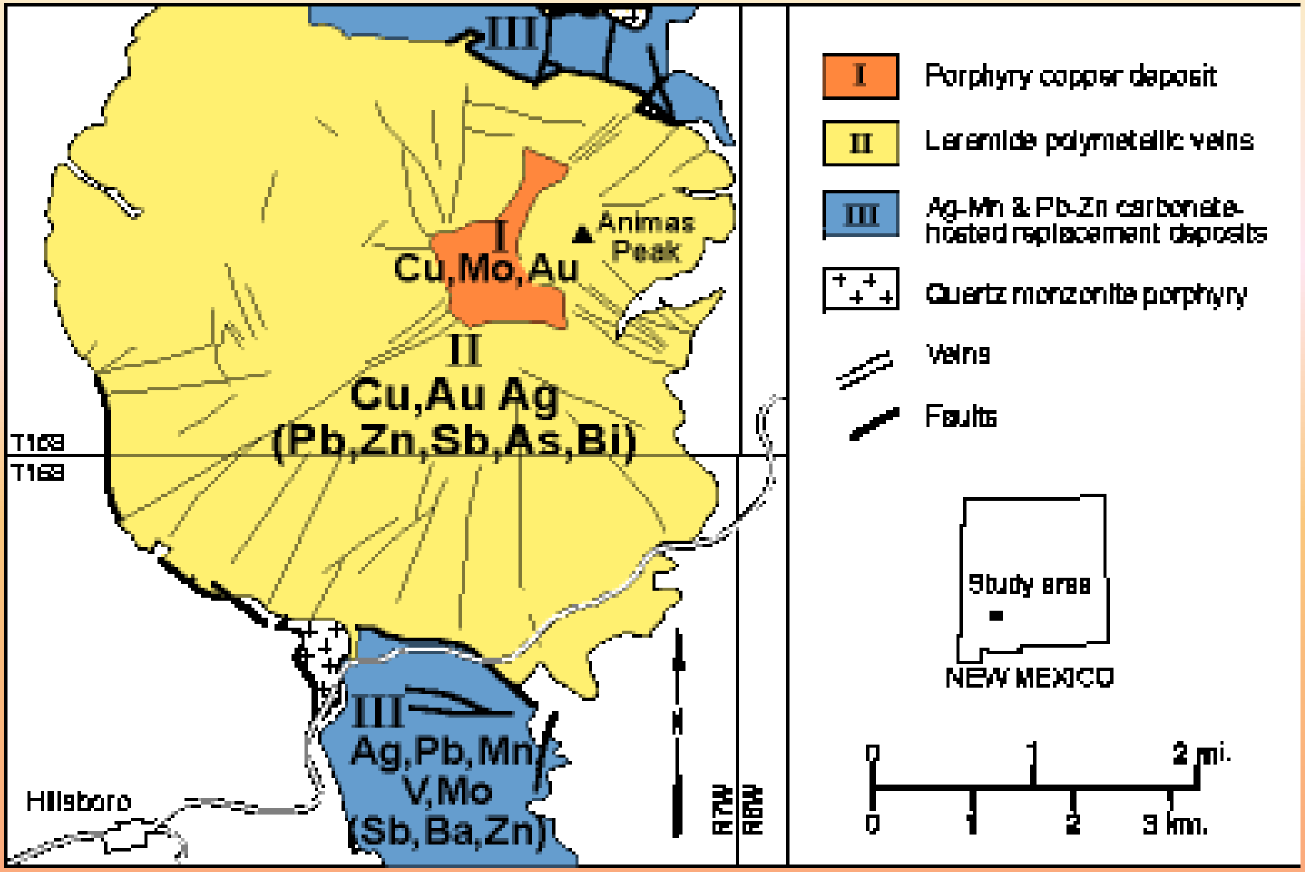
Alteration filter diagrams showing fresh and altered fields (after Wilt, 1995; Keith and Swan, 1996). Na index (a) is the ratio of Na_2O to the sum of K_2O and ACNK. ACNK is the molecular ratio of Al_2O_3 to total CaO, Na_2O, and K_2O and is calculated by $[(Al_2O_3/102)/((CaO/56)+(Na_2O/62)+(K_2O/94)]$. Potassic index (b) is the ratio of the sum of K_2O, Na_2O, and MgO by the sum of CaO and $(0.9Fe_2O_3+FeO)$. The alteration index (c) is the ratio of 100 times the sum of K_2O and MgO by the sum of K_2O, MgO, Na_2O, and CaO. The scatter in the data is a result of hydrothermal alteration. These diagrams were used to distinguish fresh from altered igneous rocks.



ALKALINE
SUBALKALINE
Na2O% + K2O%
SiO2%
a
V ppm
TiO2%
DIFFERENTIATION
b
SiO2%
TiO2%
DIFFERENTIATION
c
SiO2%
Zr(ppm)/TiO2%
DIFFERENTIATION
ALTERATION
d
latite, quartz latite dikes
mineralized quartz monzonite
quartz monzonite
andesite

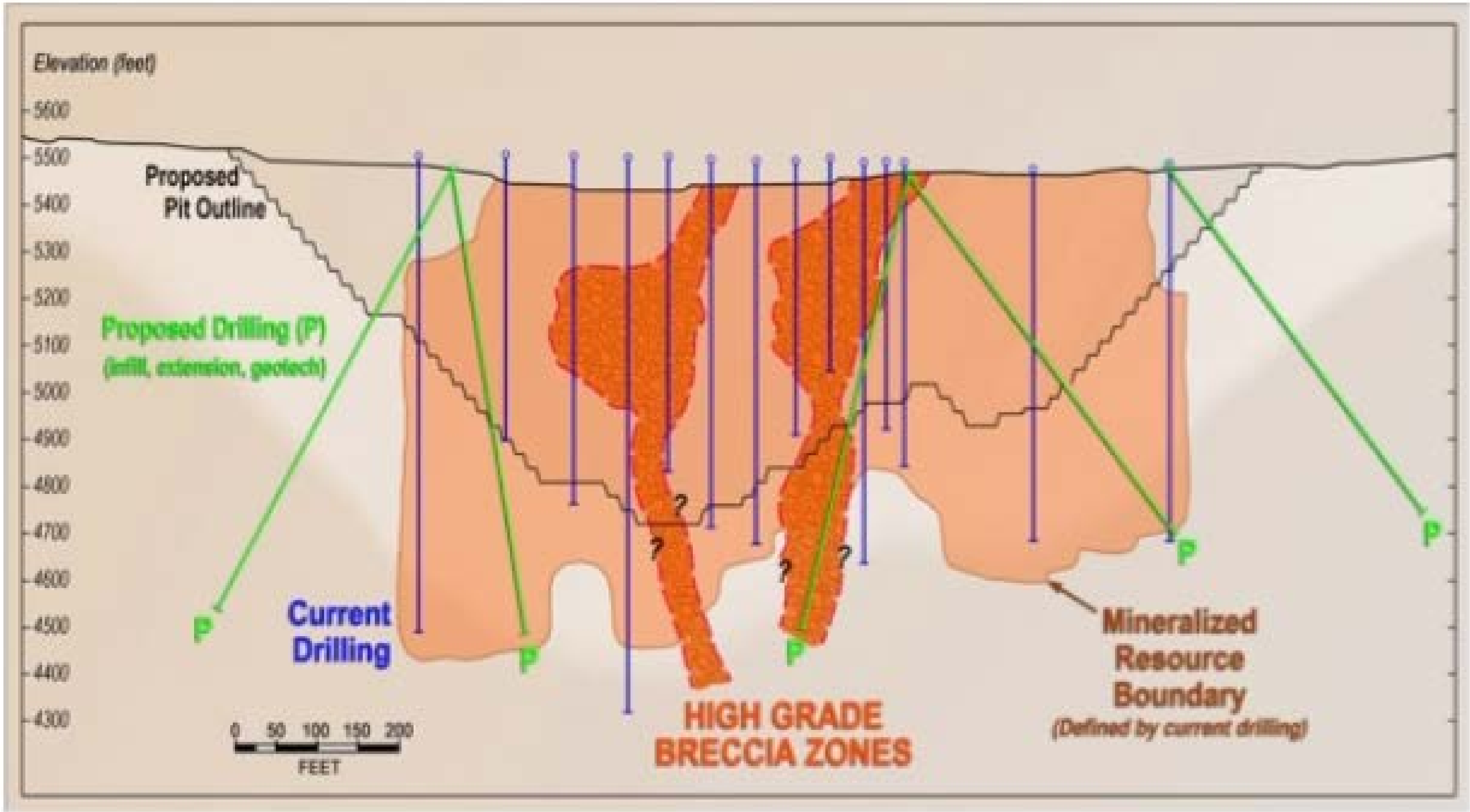


Syn-COLG
WPG
VAG
ORG
Rb (ppm)
Y (ppm) + Nb (ppm)
a
WPG
VAG+
Syn-COLG
ORG
Nb (ppm)
Y (ppm)
b
latite, quartz latite dikes
mineralized quartz monzonite
quartz monzonite
andesite



DISTRICT ZONING

- I—porphyry-copper deposit forms the center of mineralization (Cu, Mo, Au)
- II—propagating outward radially from the Copper Flat quartz monzonite are Laramide Au-Ag-Cu veins (Pb, Zn, Sb, As, and Bi) hosted by many of the latite and quartz latite dikes
- III—carbonate-hosted replacement deposits in the southern and northern parts of the district, distal from the center (Ag, Pb, Mn, V, Mo Sb, Ba, Zn)



Drilling on approximate 100-foot spacing has indicated internal continuity and consistency of grade

Chemistry

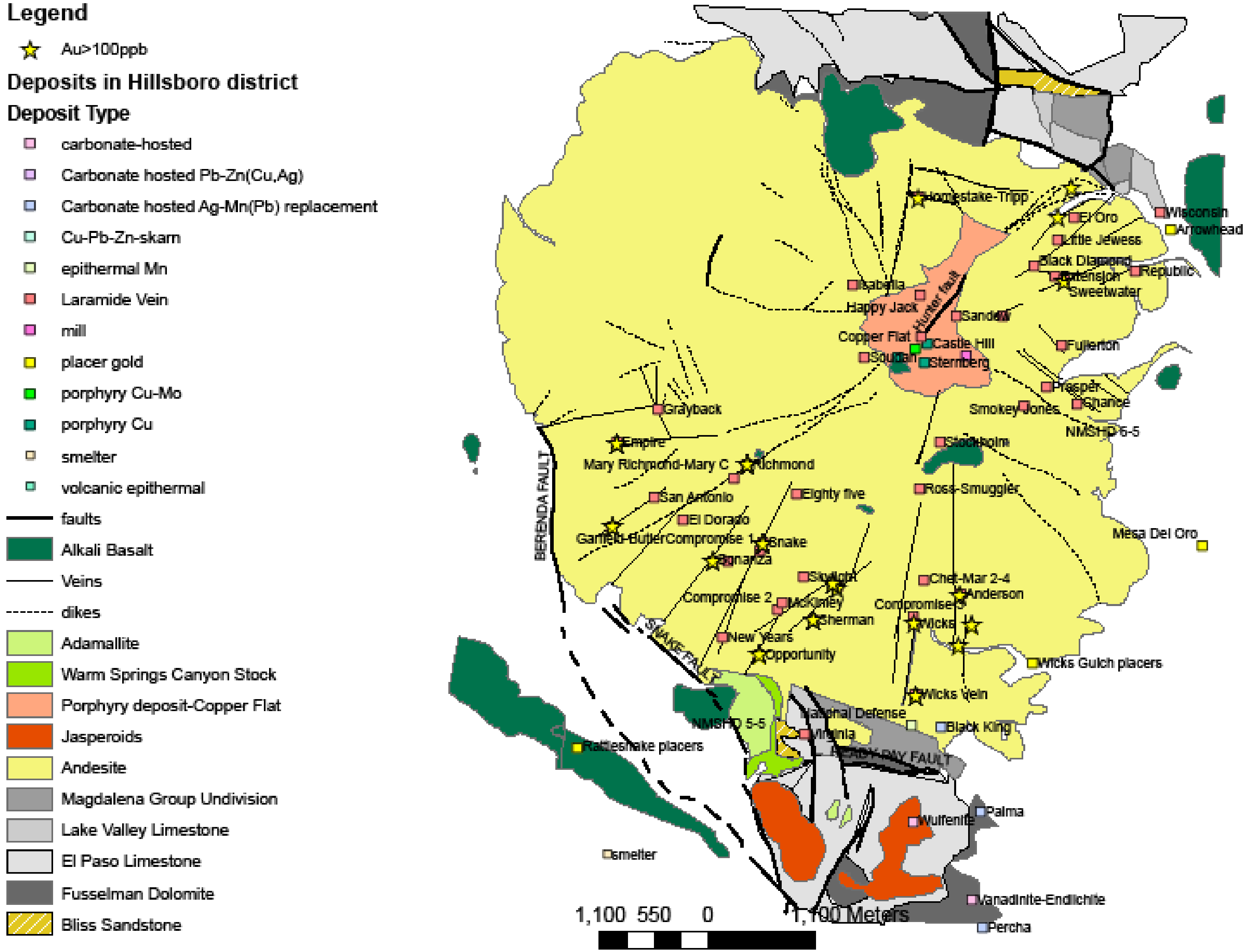
Laramide veins

- 8-64,600 ppb Au
- <0.2-590 ppm Ag
- 40-57,337 ppm Cu
- <1-475 ppm Mo
- 57-8906 ppm Pb
- 138-17,026 ppm Zn
- Recent drilling 40 ppm Te in veins

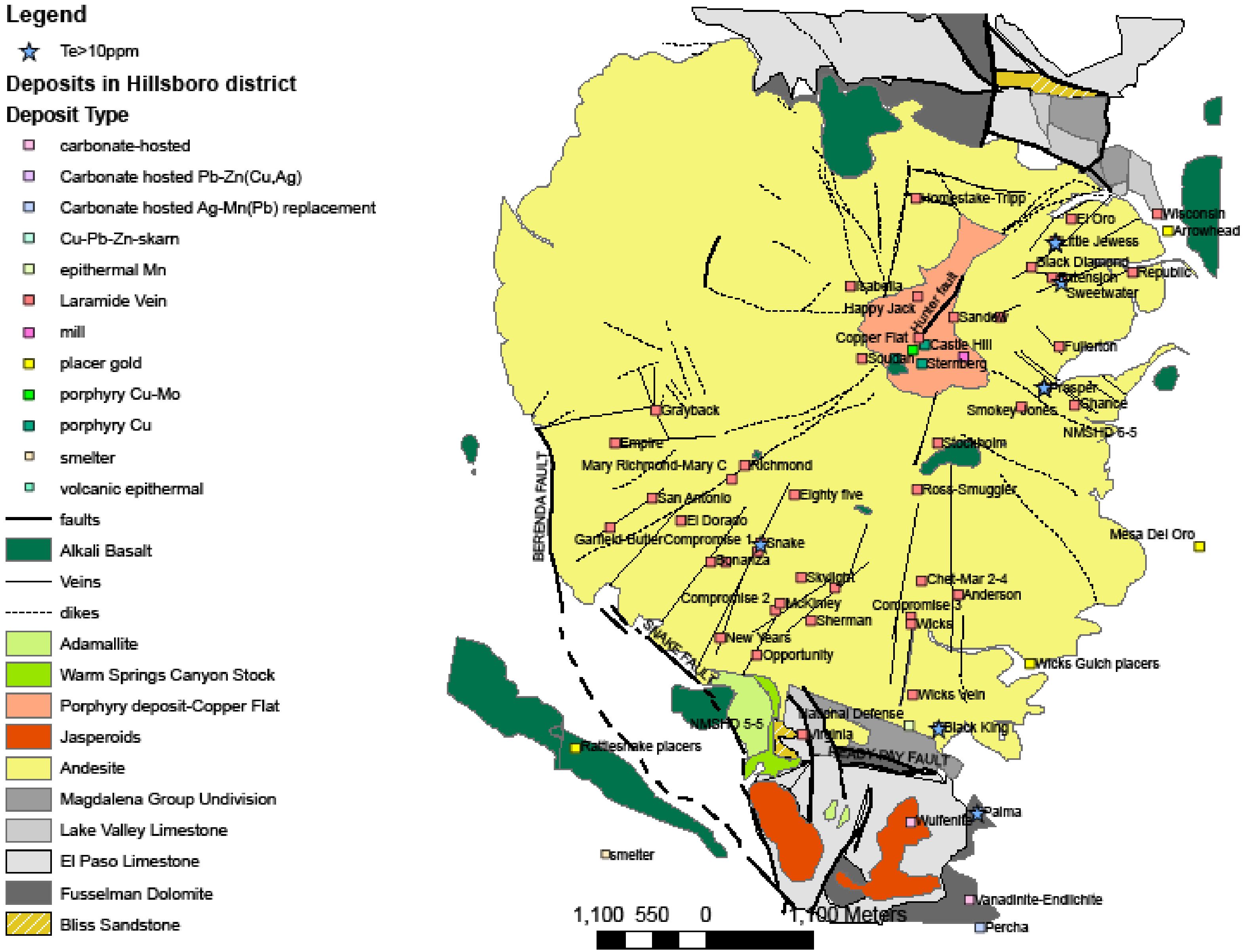
Carbonate-hosted replacement deposits

- <5-99 ppb Au
- 1-<50 ppm Ag
- 131-173 ppm Cu
- 2-140 ppm Mo
- 30->10,000 ppm Pb
- 123->20,000 ppm Zn
- <130 ppm Te
- <3400 ppm Bi

ANOMALOUS GOLD LOCATIONS

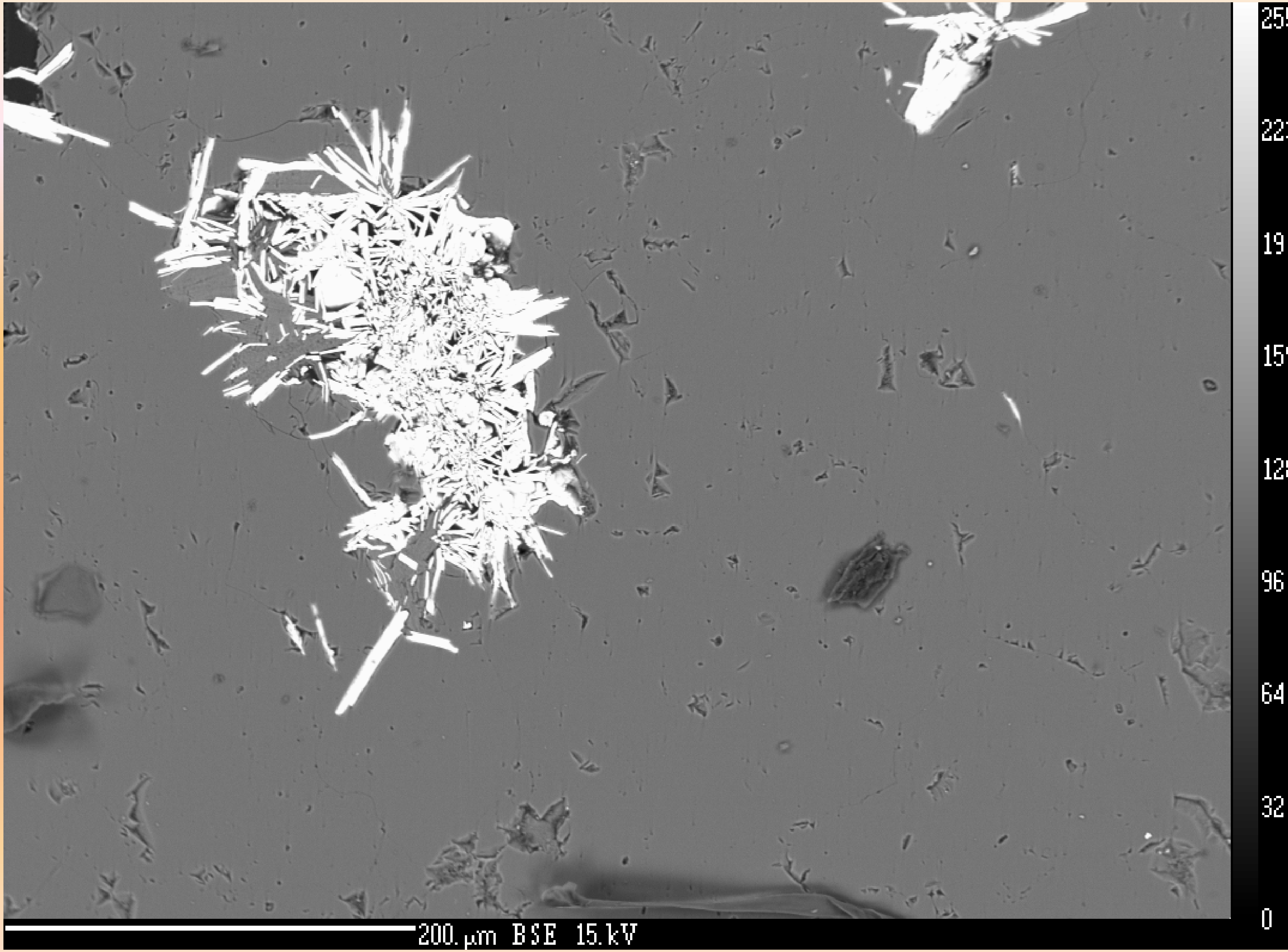


ANOMALOUS TELLURIUM LOCATIONS

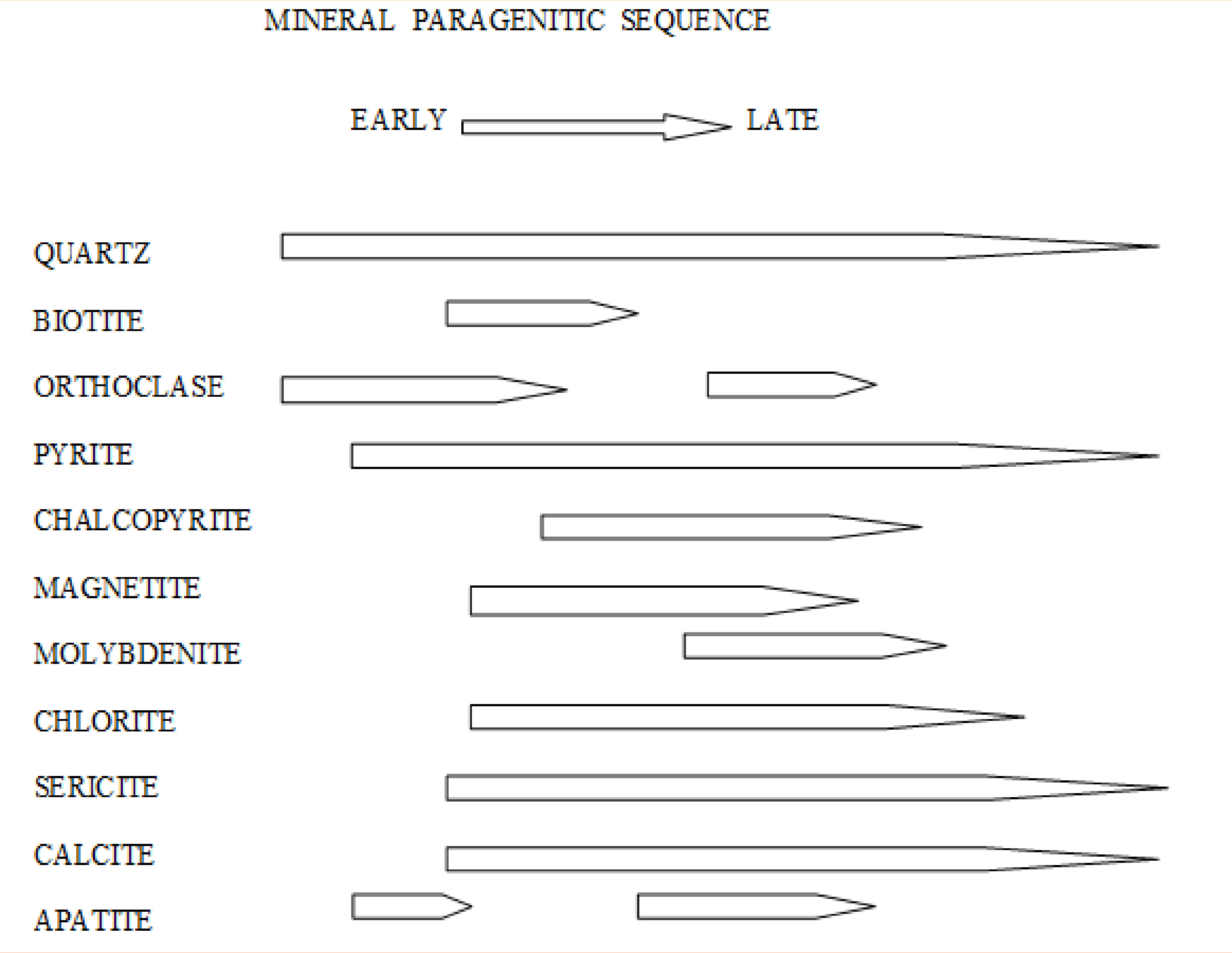


Microprobe studies

- Au and Ag were identified
- Au, Ag, and Mo are found in sulfides
- Molybdenite
- But Te, Se, Cd, Bi, and As are not detected



Back scattered image of molybdenite


MINERAL PARAGENITIC SEQUENCE
EARLY
LATE
QUARTZ
BIOTITE
ORTHOCLASE
PYRITE
CHALCOPYRITE
MAGNETITE
MOLYBDENITE
CHLORITE
SERICITE
CALCITE
APATITE

Sequence of Events

- Eruption of andesite volcano (75 Ma)
- **Intrusion of quartz monzonite porphyry and formation of breccia pipe deposit (75 Ma)**
- Latite and quartz latite dikes (70-75 Ma)
- Formation of jasperoids (35-75 Ma)
- Burial? or possibly minor erosion? (35-75? Ma)
- Eruption of Sugarlump and Kneeling Nun Tuffs (Emory caldera) (35-34 Ma)
- Uplift of the Copper Flat volcanic/intrusive complex followed by erosion (21-22 Ma)
- Eruption of alkali basalt (4 Ma)

Summary

- Need more work to determine where Te resides

Te-rich **ferromanganese crusts**

- Hydrogenetic ferromanganese oxyhydroxide crusts (Fe-Mn crusts) precipitate out of cold ambient ocean water onto hard-rock surfaces (seamounts, plateaus, ridges) at water depths of about 400 to 4000 m throughout the ocean basins

Areas of Major Potential in the US

- Ducktown, TN (**Massive Sulfides**)
- Leadville, CO (**Massive Sulfides**)
- Joplin, MO (**Massive Sulfides**)
- WV, IL, IN (High-Sulfur Coal Waste Dumps)
- Hydrothermal Deposits (CA, NV, CO, NM, …)

- **Note: World's best may be mountainous Cu-slag heaps on Cyprus (*e.g.*, Troodos)**

ECONOMICS Te

Exploration methods

- Gravimetric
  - Many are surrounded by mafic alkaline rocks (gravity high) or sedimentary rocks (gravity low)
- Geochemical
- Drilling, trenching

Exploration methods

- The Au-Ag-Te and the Te-Bi mineral assemblages may be an indicator for the size of the ore deposit.
- When Au occurs exclusively as tellurides (calaverite or Au-Ag tellurides (sylvanite, krennerite) at the intrusion outskirts, as in the case of Au-Ag Emperor Mine, calaverite precipitates in fissures on the margins of the igneous body, followed by later Au-Ag tellurides.

Exploration methods

- The economic feasibility is also indicated by the Bi and Te content; for instance, when such contents are around or below 10 ppm, the mineralization is economically uninteresting.
- When concentrations span between 10 and 300 ppm, the ore deposit is economic, subject to the reserves and mining capacity.
- Values over 300 ppm are economically interesting regardless of mining capacity.

Exploration methods

- The zoning of Te-Bi ore deposits is less known to many geologists.
- Two aspects of zoning should be underlined; one refers to the vertical zoning with respect to the intrusive bodies, as in the case of Larga ore deposit in Metaliferi Mts., where the Au-Te zone is located in the upper part, whereas the Te-Bi zone occurs at 1 km in depth, marginal to the intrusive body. In Henan province, China, the Au-Te mineralization lies between 2 and 10 km lateral to the intrusive body.

Mining

- Underground
- Porphyry copper deposits are open pit

Production Necessities

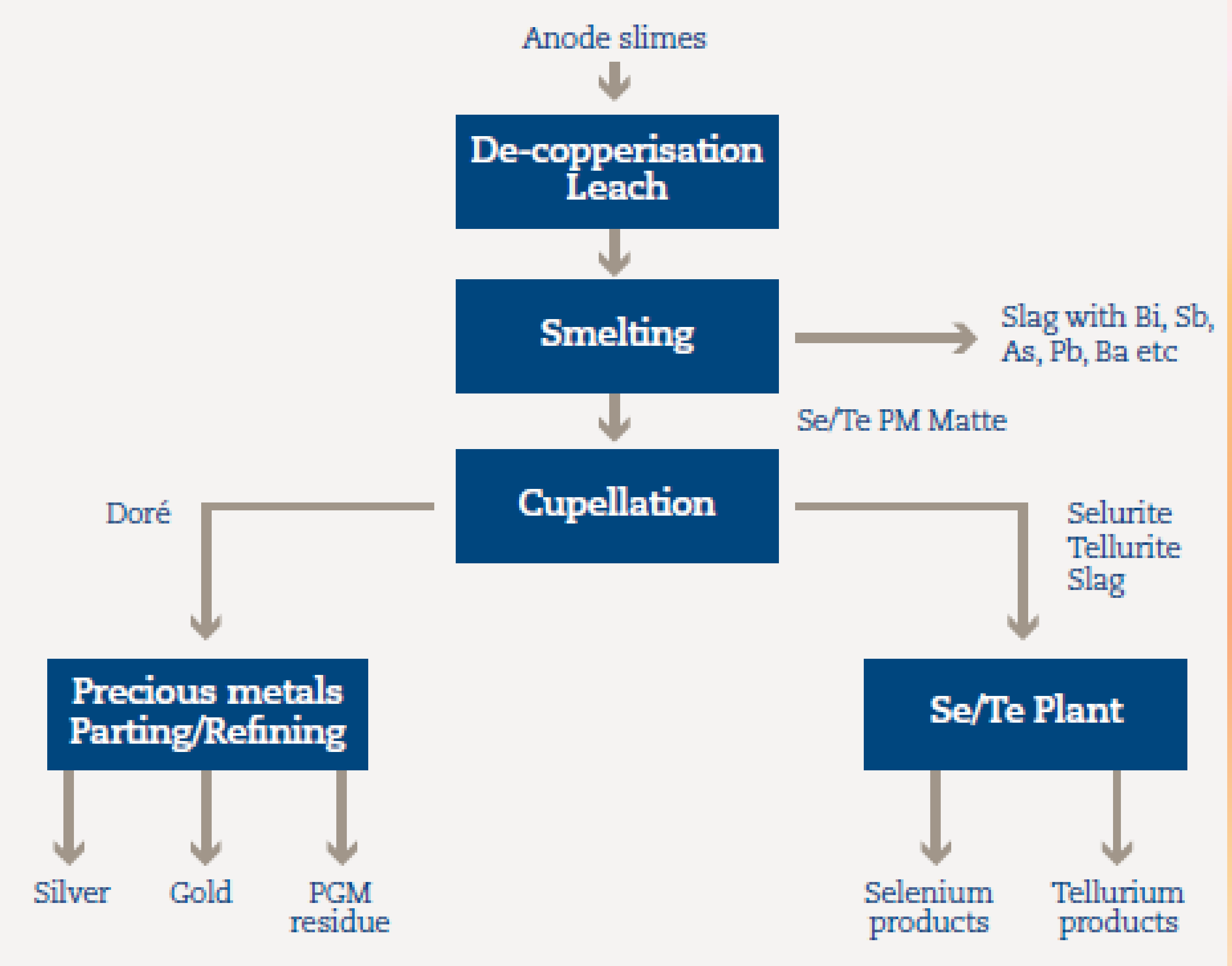
- Existence of desired commodities in economic concentrations, etc.
- Logistics (roads, electrical, water, labor, …)
- Availability of properties for mining
- Financing
- Permitting (regulations & legalities)
- **An assured long-term market**

PROCESSING

PROCESSING

- Electrolytic Copper Refining-Anode Slime Processing
- Lead Refining-Soda Slag Processing
- Platinum Group Metals Refining -Nickel/Copper Leaching
- Gold Milling-Gold/Telluride Processing

Tellerium from copper anode slimes



Source: Ullman & Bohnet (2012)

Substitutions

- Se, Bi, Pb can substitute in some metallurgical uses
- Se, S can substitute in rubber

Environmental issues

- No case histories
- Pyrite is generally presence=acid drainage potential
- If U and Th are present=radioactive wastes

Economic risks

- Less than 1 in 10,000 deposits become mines
- Estimated 1 in 2,000 or 3,000 prospects become mines
- Ore processing is very deposit specific because of the mineralogy

Recommendations

- Detailed geochemical analyses of all potential Te deposits to find out where Te resides
- Develop specific geologic models on how tellurium deposits form and how to explore for them
- Continue research on mineralized areas and mine/smelter waste dumps, etc., to enable generation of reasonable supply/demand data

ASSIGNMENT

- Barker, J. M., and McLemore, V. T., 2005, Sustainable development and Industrial minerals: Mining Engineering, December, p. 48-52, http://geoinfo.nmt.edu/staff/mclemore/documents/sustdevIM.pdf
- McLemore, V. T., and Dennis Turner, D., 2006, Sustainable development and exploration: Mining Engineering, February, p. 56-61, http://geoinfo.nmt.edu/staff/mclemore/documents/sustdev.pdf